# COTTON LEAF GRADE AS INFLUENCED BY HARVEST AID REGIMES AND CULTIVAR CHARACTERISTICS

A Dissertation

by

ZACHARY PHILLIP EDER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

| | |
|---|---|
| Chair of Committee, | G.M. Morgan |
| Committee Members, | J.T. Cothren |
| | J.A. Thomasson |
| | C.W. Smith |
| Head of Department, | D.D. Baltensperger |

August 2013

Major Subject: Agronomy

ABSTRACT

Cotton, *Gossypium hirsutum* L., leaf grade values can significantly increase with remnants of leaf and bract materials, and can result in increased ginning costs and discounts to the producer. Cotton classed through the USDA-AMS Classing Office in Corpus Christi, Texas has reported increases in leaf grade values beginning in 2000 (USDA, 2012). The impacts of the interaction of agronomic characteristics of cotton cultivars with those of various harvest aid regimes were studied over three growing seasons, and data were used to narrow possible contributors to the observed increased leaf grade values. Multiple trials were conducted throughout the Coastal Bend and Blackland Prairie of Texas, in addition to Tifton, Georgia. Cotton was harvested, lint samples were ginned in a microgin, and lint quality was quantified with HVI. Harvest aid regimes selected provided a broad range of defoliation and desiccation, from a multiple herbicidal and hormonal modes-of-action. Defoliation levels ranged from 0 to 96% and desiccation levels ranged from 0 to 90%. Harvest aid treatments had no impact ($P \leq 0.05$) on leaf grade values for either of the years of the trials. Multiple trials were conducted in five counties in Texas, including the Lower and Upper Coastal Bend and the Blackland Prairie, and were defoliated with a uniform harvest aid treatment to identify leaf and bract morphological differences, and to determine their role in leaf grade. Multi-acre module trials were conducted with a smooth leaf cultivar and a hairy leaf cultivar to obtain leaf grade values following commercial ginning. Leaf and bract pubescence, and leaf and bract area were collected to analyze the resulting impact on cotton leaf grade values. Visual quantification of leaf and bract trichome density was quantified on 10 youngest fully-expanded leaves and 10 mid-canopy full sized bolls, respectively, when cotton was at physiological cut-out. Trichome density quantification indicated substantial variation in cultivars and discrepancies from company based rating systems. Leaf grades values generally increased with increasing trichomes densities, although not always statistically significant. In the split plot cultivar and harvest aid trial, harvest aid efficacy was similar for each of the cultivars, but cultivar trichome density was positively influence the cotton leaf grade value.

DEDICATION

This dissertation is dedicated to my beautiful wife, Sarah, for her curiosity of the world drives my desire to find answers. To my father, Victor, who started me on this journey 26 years ago, by sharing his unending love for agriculture and determination in the face of monumental tasks.

ACKNOWLEDGEMENTS

I am incredibly grateful to my committee chair and advisor, Dr. Gaylon Morgan, for providing the opportunity, and support, to purse my graduate studies at Texas A&M University. My appreciation also goes to my committee members, Dr. J. Tom Cothren, Dr. Alex Thomasson, Dr. C. Wayne Smith, and Dr. Dan Fromme, for their guidance and support throughout the course of this research. Their combined efforts and encouragement during the past three years has allowed me to obtain a life-long goal.

Thanks also goes to Dale Mott and our student workers, for their tireless efforts on many long trips which made each season possible. A special thanks goes to the faculty and staff at Texas A&M University, for making my time a great experience.

I owe a special thanks to all the producers who participated in the various trials during the course of this research; without their hard work this would not have been possible.

My mother, Diane, and father, Victor, instilled in me a strong work ethic and a curious nature, and with constant encouragement, started this amazing journey. Finally, thanks to my wife, Sarah, for her faith in me through this chapter in our lives. Her enduring love made this possible.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

## Introduction

The process of preparing for harvest and harvesting cotton, *Gossypium hirsutum* L., is dynamic, and numerous factors can influence the outcome of defoliation. The successful use of defoliation products and their associated rates is commonly referred to as part “art” and part science (Supak and Snipes, 2001). Correctly pairing the different variables of defoliation products, product rates, cultivar, and environment can preserve cotton lint quality, including cotton leaf grade value. During the last decade, cotton leaf grade values, resulting from the plant material remaining after ginning, has steadily increased and remains of economic importance to producers throughout the Cotton Belt, and particularly in the Coastal Bend of Texas (USDA, 2012). From 2000 to 2012, cotton leaf grade values of 4 or greater substantially increased each year, except for 2011, when abnormally dry conditions were present during the harvest season (Appendix A). Higher cotton leaf grade values have a detrimental impact on the entire U.S. cotton industry with price reductions to the producer and increased ginning cost for ginners.

Cotton lint quality is determined by a diversity of fiber characteristics, both physical and visual, and is quantified with the High Volume Instrument (HVI) for all the cotton classed in the U.S. Some of the primary physical characteristics of fiber quality include length, strength, elongation, micronaire, and leaf grade; visual components include brightness, yellowing, and staining (USDA, 2012). Specifically, cotton leaf grade is the visual estimate of the quantity of leaf and bract material in the ginned lint sample submitted for HVI analysis at the USDA Classing Office. Leaf grade is rated with a value of 1 to 7, with 1 being the lowest leaf contamination score and 7 the highest. Leaf grade values are currently calculated with HVI using a proprietary algorithm comparing particle counts and percent area of leaf and bract content. Prior to 2011, human classers compared lint samples to universal standards to determine the cotton leaf grade value.

Several agronomic factors are believed to negatively influence the leaf grade values, including: cotton defoliation, late-season weather conditions, and some cotton cultivar characteristics (Anthony and Rayburn, 1989; Morey et al., 1976). The quantity of cotton leaves remaining on the plant at harvest time is a logical contributing factor, including green leaves and leaves desiccated during the pre-harvest application of harvest aid products (Supak and Snipes, 2001). Common late-season weather conditions detrimental to harvest includes, late-season rainfall resulting in regrowth and conditions promoting poor application coverage, and other factors decreasing harvest aid efficacy (Seibert and Stewart, 2006). Cotton cultivars can be distinctive from one another in terms of leaf size, hairiness, and growth habits and may also detrimentally impact cotton leaf grade values (Novick et al., 1991; Smith, 1964).

Cotton is a perennial plant that is agronomically grown as an annual crop. To improve harvest conditions for mechanical harvesting, harvest aid chemicals can be used to prepare the crop in the fall (Fortenberry, 1956; Lewis and Richmond, 1968). The termination and defoliation of the cotton plant has been proven to be vital to the improvement of harvest conditions, maintaining lint quality, and increasing harvest efficiency (Faircloth et al., 2004; Seibert and Stewart, 2006; Sui et al., 2010).

The interaction between the cotton and the mechanical processes of harvesting and ginning can affect fiber quality and nonlint trash (leaf content, bark, grass, etc). Mechanical harvesting has shown to decrease cotton lint quality, specifically increasing nep count and foreign matter found in the lint; however, mechanical harvesting is essential to harvest the U.S. cotton crop in a timely manner (Faulkner et al., 2008). In the U.S., mechanical harvesting consists of two different harvester types, a stripper and a spindle picker. Stripper harvesting of cotton is a nonselective process that removes mature and immature bolls with burs, bracts, leaves, and small branches. Strippers are commonly equipped with a bur extractor, which removes the majority of the larger plant material, including burs, stems and immature bolls. Bennett et al. (1997) found that bur extractors, incorporated into the harvesting process, reduced burs in cotton by 70% and sticks by 29%. Spindle picker harvesting is a more selective process that pulls the seed cotton from the open bolls and excludes immature bolls and much of the foreign plant materials. The difference in harvesting methods is another factor considered when selecting a harvest aid regime. Stripper harvested cotton must be desiccated prior to harvest with harvest aids or by a lethally low temperatures to minimize moisture in plant materials and prevent possible damage from heat during module storage (Supak and Banks, 2001).

Reducing the amount of plant material (leaf, bract, petiole, etc.) in harvested cotton through the ginning process is an important step in improving fiber quality (Sui et al., 2010). However, excessive lint cleaning to remove these plant parts can have a detrimental impact on fiber length and gin turnout (Sui et al., 2010). If the leaf and bract materials cannot be removed during the ginning process, higher leaf grade values will result in discount prices to producers. This price reduction typically begins at a leaf grade of four and results in a significant reduction of 5.95 or more cents per kg (Larson and English, 2001).

### Defoliation

Harvest aid application timing is important to the termination of a cotton crop, and is dependent on the maturity of the crop, the harvest aid regime, mode-of-action, and harvest methods. Premature defoliation can compromise cotton yield and quality due to incomplete boll development, while delaying defoliation allows for immature bolls to develop further, enhancing yield (Snipes and Baskin, 1994). However, delaying harvest aid applications and harvest can increase the risks due inclement weather and result in degraded lint quality and less harvestable cotton. In much of the Cotton Belt, the applications of harvest aid applications begin at 60-70% open bolls and 7 to 14 days prior to expected harvest.

The use of desiccants and defoliants has been intensely studied since the 1930s and continues with various research trials (Cathey, 1986; Faircloth et al., 2004; Snipes and Cathey, 1992; Walhood and Addicott, 1968). The on-going evaluation of harvest aids is the result of the unpredictability of the efficacy of harvest aid products, introduction of new products, and the importance of the process for harvest efficiency and to minimize price discount for plant materials in the lint (Valco and Snipes, 2001).

Several factors are known to impact the success of defoliation which includes: harvest aid product(s), plant condition, weather prior to, during, and following application, spray coverage, canopy density, translocation of chemicals, and varietal traits (Cathey, 1986; Oosterhuis et al., 1991). The improper choice, timing, or use of harvest aid products can negatively impact the quality by reducing the economic value by increasing staining and short fiber content, or decreasing length uniformity, and yield (Seibert and Stewart, 2006). Ineffective harvest aid application, due to product choice, rate, or timing, can result in the need for additional application(s) and result in increased production costs. Studies have investigated varying components of cotton defoliation and have found broad recommendations difficult to predict (Oosterhuis et al., 1991; Seibert and Stewart, 2006; Valco and Snipes, 2001). Furthermore, application timing and harvest aid treatments had relatively inconsistent effects on trash and leaf grade when compared on ultra-narrow row cotton (Larson et al., 2005). Additional inconsistencies were found by Seibert and Stewart (2006) when comparing different cotton fields, which resulted in the conclusion that harvest aid selection, should be based on individual fields and environments.

Similar to other dicot plants, the natural physiological process of leaf senescence involves the increased production of ethylene and other precursors that down regulate auxin production within the leaf which promotes the abscission layer formation (Guinn, 1986; Morgan, 1984; Morgan and Durham, 1975). Application of defoliation products promotes the development of ethylene production and leaf senescence from the cotton plant (Addicott, 1982; Sexton et al., 1985; Cathey, 1986). Harvest aid products have several different modes-of-action, which can impact the overall efficacy (Siebert, et al. 2006). Hormonal harvest aids produce senescence by directly promoting ethylene evolution within the plant (Suttle, 1988). Defoliants, such as, ethephon, thidiazuron, cyclanilide, dimethipin, and others, interact with plant cells to promote ethylene production in different ways. Herbicide based harvest aid products injure the plant and promote an ethylene response, which results in leaf abscission. Desiccating harvest aid products include paraquat and sodium chlorate, both which are strong contact based herbicides that have limited translocation (Scandalios, 1993). With both herbicidal and desiccant harvest aid products, when the abscission layer does not fully form prior to the desiccation of the leaf; the desiccated leaves remain tightly attached to the plant. This can result in a dry, dead leaf attached to the plant at the time of harvest and will be pulled into the harvester along with the seed cotton. When evaluating harvest aid products, these desiccated leaves are rated as the percentage of total leaves on the plant. Drying of the leaves can be very important in reducing moisture during the storage of modules, specifically for stripper harvested cotton.

Different harvest aid products can be combined to synergize the effects of the active ingredients, and this can occur at the product level or as a tank mix. For example, thidiazuron and diuron are combined into a single product, where thidazuron inhibits auxin transportation, while diuron promotes ethylene production by inhibiting photosynthesis and promoting stress within the cell (Suttle, 1988, Zer and Ohad, 1995). Regardless of the product or mode-of-action, leaf removal by any of these harvest aid products will result in a plant with a reduced amount of leaf canopy at harvest time and increase harvest efficiency.

## Cultivar Morphology

Leaf grade values of the ginned lint can be impacted by the plant pubescence, or hairiness, of the cotton cultivar, which is determined by the presence and density trichomes (Anthony and Rayburn, 1989; Rayburn, 1988). Trichomes are hair-like protrusions on the surface of the plant parts (Bradow and Wartelle, 1998; Oosterhuis and Jernstedt, 1999). Cotton trichomes on leaves, leaf margins and stems are genetically controlled by multiple alleles at five loci (Percy and Kohel, 1999). Some of these alleles can affect different plant tissues and organs. Trichome densities between different regions of the leaf have strong positive correlations to each other (Smith, 1964).

Both Rayburn (1988) and Anthony and Rayburn (1989) compared smooth and hairy cultivars together to determine the effect on trash remaining in the lint following ginning. Lint from smooth leaf cultivars was easier to clean during the ginning process and thus had lower leaf grade values (Rayburn and Libious, 1983; Anthony and Rayburn, 1989). Leaf trichome density also has other implications on cotton management. An increase in the density of trichomes of a cotton cultivar has been reported to influence the preferential feeding of some insect pests (Lecape and Nguyen, 2005). Mekala (2013) reported cotton fleahoppers density increased with increasing trichome density. Jenkins and Wilson (1996) and Norman and Sparks (1997) reported increased susceptibility to whiteflies for cotton cultivars with more dense trichomes and an increased insecticide applications to control whiteflies.

Bracts are modified leaves that surround the developing flower bud and boll on the cotton plant. Cotton bracts are a major contributor to leaf trash in harvested lint (Morey et al., 1976). Alteration of the bract morphology has been attempted by breeders in the past. However, bract size reduction, or reducing their persistence, has shown to negatively impact the overall plant physiology, and relative bract size is influenced by environmental conditions, such as drought (Bourland and Hornbeck, 2007; Wullschelger et al., 1990; Zhao and Oosterhuis, 2000).

Current universal industry standards for leaf trichome density ratings do not exist, and all ratings are subject to a company's proprietary process and scale as leaf hairiness. Norman and Sparks (1997) found that while some cultivars maintained stable trichome densities over multiple years, many have wide variations across years. Standard trichome ratings have been proposed by various sources, but none have been fully adopted by the cotton industry (Bourland and Hornbeck, 2007; Smith, 1964; Rayburn, 1986). Smith (1964) evaluated cotton trichomes grown in Alabama and found a range of 2 to 205 trichomes $cm^{-2}$, where a Deltapine Smooth Leaf cultivar was viewed as the standard for the smooth leaf cultivar in his ratings. To study cotton hairiness, Rayburn (1986) separated cultivars into smooth and hairy categories, prior to the development and commercial release of reduced hairy cultivars that were an intermediate in hairiness. Rayburn (1986) quantified leaf trichomes, and proposed a three class system of "smooth", "moderately hairy", and "hairy". Bourland et al. (2003) noted that following this study the release and classification of multiple cultivars as "reduced hair" became available to Delta producers as "semi-smooth" cultivars. The most objective rating method published is the quantification of the trichomes proposed by Bourland et al. (2003), where trichome density is quantified at the base of the leaf on the abaxial side. However, quantification of leaf trichome densities has not been adopted by the industry, in part, due to the time required to quantify the trichome density. Bourland et al. (2003) developed a visual rating system for leaf hairiness (1-9) based on abaxial leaf trichome density. Bourland and Hornbeck (2007) proposed another method that increased the efficiency of leaf hairiness ratings, but their methodology was subjective and has not been widely adopted.

Variation between seasons and within a single plant depending on the location within the canopy has been found in leaf trichome density (Bourland et al., 2003). Minimizing variation by utilizing uniform collection methods is vital to proper rank analysis of cultivars. Bourland et al. (2003) collected leaf samples from three canopy regions and compared trichome densities. The trichome density decreased on more mature leaves and was attributed to the physical wearing off of the trichomes. Therefore, Bourland et al. (2003) identified the leaves five nodes from the apex, the first fully expanded leaf, as the best representation of the plant’s trichome density. Dimitropoulou et al. (1980) found differences in trichome densities between cultivars when studying the distribution of bract trichomes on the abaxial and adaxial surfaces rather than marginal trichomes. Additional testing on marginal bract trichome density found that mid-canopy, first position bolls were the best representation of bract trichomes (Bourland and Hornbeck, 2007; Hornbeck and Bourland, 2007). The relationship between bract trichome density and leaf trichome density were positively correlated, with values of 0.35 and 0.33 in 2001 and 2002, respectively, within a segregating $F_2$ population (Hornbeck and Bourland, 2007).

## Objectives

The primary objective of this study is to identify the cause of increasing cotton leaf grade values in the Gulf Coast Region of Texas. The specific objectives are 1) To identify the impact of leaf defoliation and desiccation levels on cotton leaf grade; 2). To identify key cultivar characteristics, such as leaf and bract trichome density, that contributes to increased cotton leaf grade values; and, 3). To identify the key interactions between harvest aids and cultivar characteristics on cotton leaf grade values.

# CHAPTER II

# COTTON LEAF GRADE AS INFLUENCED BY COTTON HARVEST AID REGIMES

## Overview

Defoliation of cotton, *Gossypium hirsutum* L., has been referred to as more art than a science by industry leaders (Supak and Snipes, 2001). The remnants of leaf material in ginned cotton can significantly increase leaf grade values and result in price discounts to the producer. Cotton classed through the USDA-AMS Classing Office in Corpus Christi, Texas has reported increases in leaf grade values beginning in 2000, which have resulted in significant financial losses to Texas producers and ginners (Appendix A). The impacts of the harvest aid and agronomic variables were studied during the 2010 to 2012 growing seasons and data were collected to identify possible contributors to increasing leaf grade values, including leaf trichome density and harvest aid treatments. Trials were conducted in Colorado, Matagorda, and Burleson Counties. A broad range of defoliation and desiccation levels were achieved by applying over 16 diverse harvest aid treatments that included herbicidal, desiccants, and hormonal modes-of-action. The defoliation levels ranged from 0 to 96%, and leaf desiccation levels ranged from 0 to 90%, but were variable by year. Seed cotton subsamples from spindle picker harvested plots were ginned on a microgin, and fiber analyses were conducted using HVI. Median leaf grade levels for Burleson County were 3, 1, and 3 for 2010, 2011, and 2012, respectively. Coastal Bend leaf grade median levels were, 4, 1, and 2, for the same three years. Overall leaf grades were lower in 2011 and were likely due to less precipitation late in the season and specifically between harvest aid application and harvesting. Despite the substantial range in leaf defoliation and desiccation levels, harvest aid treatments had no impact ($P \leq 0.05$) on leaf grade values for either location or year of this trial.

## Introduction

The process of preparing for harvest and harvesting cotton, *Gossypium hirsutum* L., is ever changing, and numerous factors can influence the outcome of defoliation. The successful use of harvest aid products and their associated rates is commonly referred to as part "art" and part science (Supak and Snipes, 2001). During the last decade, cotton leaf grade, the plant material remaining after ginning, has steadily increased and remained a hindrance to producers throughout the Cotton Belt, and particularly in the Coastal Bend of Texas (USDA, 2012). From 2000 to 2010, cotton leaf grade values of 4 or higher substantially increased each year, but decreased sharply in 2011, due to abnormally dry conditions present during the harvest season. Higher cotton leaf grade values have a detrimental impact on cotton the entire U.S. cotton industry with price reductions to the producer and increased ginning cost for ginners.

Cotton lint quality is determined by a diversity of fiber characteristics, both physical and visual with the High Volume Instrument (HVI) for all the cotton classed in the U.S. Some of the primary physical characteristics of fiber quality include length, strength, elongation, micronaire, and leaf grade; visual components include brightness, yellowing, and staining (USDA, 2012). Cotton leaf grade is the visual estimate of the quantity of leaf and bract material in the lint sample submitted for HVI analysis. The leaf grade is rated on a scale of 1 to 7, with 1 being the lowest contamination score and 7 the highest. Leaf grade values are currently calculated for HVI using a proprietary algorithm comparing particle counts and percent area of trash. Prior to 2011, human classers compared lint samples to universal standards to determine the cotton leaf grade value.

Reducing the amount of plant material (leaf, bract, petiole, etc.) in harvested cotton through the ginning process is an important step in improving fiber quality (Sui et al., 2010). However, excessive lint cleaning to remove these plant parts can have a detrimental impact on fiber length and gin turnout (Sui et al., 2010). If the leaf and bract materials cannot be removed during the ginning process, higher leaf grade values will result in discount prices to producers. This price discount typically begins at a leaf grade of four and results in a significant reduction of 5.95 or more cents $kg^{-1}$ (Larson and English, 2001).

Cotton is a perennial plant that is grown as an annual agronomic crop. To improve harvest conditions for mechanical harvesters, harvest aid products can be used to prepare the crop in the fall (Lewis and Richmond, 1968; Fortenberry, 1956). The termination and defoliation of the cotton plant has been proven to be vital to the improvement of harvest conditions, maintaining lint quality, and increasing harvest efficiency (Sui et al., 2010; Faircloth et al., 2004; Seibert and Stewart, 2006). Harvest aid application timing is important to the termination of a cotton crop and is dependent on the maturity of the cotton crop and the harvest aid regime, mode-of-action and harvest methods. Premature defoliation can compromise cotton yield and quality due to incomplete boll development, while delaying defoliation allows for immature bolls to develop further, enhancing yield (Snipes and Baskin, 1994). However, delaying harvest aid applications and harvest can increase the risks and reduce yield due inclement weather, such as heavy rain or high winds. In much of the Cotton Belt, the application of harvest aid applications begins at 60 to 70% open bolls and 7 to 14 days prior to expected harvest.

The use of desiccants and defoliants has been intensely studied since the 1930s and continued for some time with the Cotton Defoliation Work Group (Cathey, 1986; Faircloth et al., 2004; Snipes and Cathey, 1992; Walhood and Addicott, 1968). The on-going evaluation of harvest aids is the result of the unpredictability of the efficacy of harvest aids, and the importance of the process for harvest efficiency and to minimize price discount for plant materials (Valco and Snipes, 2001).

Several factors are known to impact the success of defoliation and include harvest aid product(s), plant condition, weather prior to, during, and following application, spray coverage, canopy density, translocation of chemicals, and varietal traits (Cathey, 1986; Oosterhuis et al., 1991). The improper choice, timing, or use of harvest aid products can negatively impact the fiber quality, and reduces the economic value of the crop by increasing staining and short fiber content, or decreasing length uniformity, and yield (Seibert and Stewart, 2006). Ineffective treatments, due to product choice, rate, or timing, can result in the need for additional treatments and result in increased production costs. Studies have investigated varying components of cotton defoliation and have found broad recommendations difficult to predict (Oosterhuis et al., 1991; Seibert and Stewart, 2006; Valco and Snipes, 2001). Cathey (1986) reported the plant condition and environmental factors during application were directly correlated with success of a harvest aid application. For instance, purposely terminating cotton early in the season at 361 degree days, base 15.6 degrees C, (DD) after cut-out had a higher leaf grade value than defoliation at 512 DD due to a reduced amount of defoliation of earlier treatment (Larson et al., 2002). However, application timing and harvest aid treatments had relatively inconsistent effects on trash and leaf grade when compared on ultra-narrow row cotton (Larson et al., 2005). Additional inconsistencies were found by Seibert and Stewart (2006) when comparing different cotton fields, which resulted in the conclusion that harvest aid selection should be based on individual fields and environments.

Similar to other dicot plants, the natural physiological process of leaf senescence involves the increased production of ethylene and other precursors that down regulate auxin production within the leaf which promotes the abscission layer formation (Guinn, 1986; Morgan, 1984; Morgan and Durham, 1975). Application of defoliation products promotes the development of ethylene production and results in leaf senescence from the cotton plant (Addicott, 1982; Sexton et al., 1985; Cathey, 1986). Several different modes-of-action are currently available in harvest aid products, which can impact the overall efficacy (Siebert, et al. 2006). Hormonal harvest aids produce senescence by directly promoting ethylene evolution (Suttle, 1988). Defoliants, such as ethephon, thidiazuron, cyclanilide, dimethipin, and others, interact with plant cells to promote ethylene production in different ways. Herbicide based harvest aids injure the plant and promote an ethylene response, which results in leaf abscission. Desiccation harvest aid products include paraquat and sodium chlorate, both which are strong contact based herbicides that have limited translocation and can cause significant desiccation (Scandalios, 1993). With an inappropriate rate of both herbicidal and desiccant harvest aid products, the abscission layer may not fully form prior to the desiccation of the leaf, and the desiccated leaves remain attached to the plant. This desiccated leaves will be pulled into the harvester along with the seed cotton and will be entangle with the seed cotton. When evaluating harvest aid products, these desiccated leaves are rated as the percentage of total leaves on the plant.

Different chemistries can be combined to synergize the effects of the active ingredients, and this can occur at the product level or as a tank mix. Thidiazuron and diuron are combined into a single product, to inhibit auxin transport using thidiazuron, and promoting ethylene production by diuron inhibiting photosynthesis and promoting stress within the cell (Suttle 1988; Zer and Ohad, 1995). Regardless of the product or mode-of-action, leaf removal by any of these modes-of-action will result in a plant with a reduced amount of leaf canopy at harvest time and increase harvest efficiency.

This study was designed to determine the impact of cotton defoliation and desiccation on cotton leaf grade values. A wide range of defoliation and desiccation levels are needed to properly identify an impact on leaf grade.

## Materials and Methods

### *Cultural Practices*

Comparisons of harvest aid treatments and their impact on leaf grade value were conducted from 2010 to 2012 in the Coastal Bend of Texas, Colorado and Matagorda Counties, and at the Texas A&M AgriLife Research Farm in Burleson County. Soil types were a Norwood silty clay loam (fine-silty, mixed, superactive, hyperthermic fluventic eutrudepts) in Colorado County during the 2010 and 2012 growing seasons, a Laewest clay (fine, smectitic, hyperthermic typic hapluderts) in Matagorda County during the 2011 growing season, and Weswood silt loam (fine-silty, mixed, superactive, thermic, Udifluventic Haplustepts) in Burleson county for all years of the study. Cotton (*Gossypium hirsutum* L. cv. 'Phytogen 375 WRF') was planted and managed under local practices recommended by the Texas A&M AgriLife Extension Service. Supplemental irrigation was used as needed in the Burleson County location all seasons to ensure average yields. In Colorado County the trial was irrigated and non-irrigated in 2010 and 2012, respectively. The Matagorda County location was a non-irrigated site. Below normal precipitation occurred at all locations in 2011. All trial plots were four rows (1.02 m wide) by 12.2 m long. An alley way was cleared of vegetation between each replication during mid-season to prevent across treatment contamination during harvest aid application and harvest. Precipitation and temperature data for each location are included in Appendix B.

*Treatment Application and Experimental Design*

Harvest aid treatments were arranged in a randomized complete block design with four replications. In 2010, twenty harvest aid treatments were applied to obtain a wide range of defoliation and desiccation levels at Colorado and Burleson counties. In the 2011 and 2012 studies, sixteen harvest aid treatments were selected from those used in 2010 (Table 1). Each trial contained an untreated check treatment, where water was applied to the appropriate plots. Per the product label recommendations, non-ionic surfactant was used at a 0.25% v/v rate in treatments containing carfentrazone-ethyl and pyraflufen ethyl, and crop oil concentrate was used in treatments containing paraquat (Table 1).

Treatments for all studies were applied with a four row Lee Spider sprayer with a spray volume of 103 L $ha^{-1}$ using XR flat fan tips at a boom height of 46 cm above the average canopy height. All four rows of the experimental plot were sprayed in one pass by the sprayer. The initial harvest aid application was applied 14 days prior to expected harvest, when the crop had approximately 65% open bolls. All sequential applications were applied seven days after the initial application and one week before harvest.

Table 1. Chemical treatments used in harvest aid comparison trials.

| ID | Treatment [z] | g AI $ha^{-1}$ | Timing | 2010[y] | 2011 | 2012 |
|---|---|---|---|---|---|---|
| 1 | Thidiazuron | 56 | A[v] | X | X | X |
| | Thidiazuron | 56 | B | | | |
| 2 | Thidiazuron | 28 | A | X | X | X |
| | Ethephon | 2205 | A | | | |
| 3 | Ethephon | 1103 | A | X | | |
| 4 | Thidiazuron | 28 | A | X | | |
| 5 | Thidiazuron | 112 | A | X | X | X |
| 6 | Thidiazuron | 56 | A | X | | |
| | Ethephon | 1103 | A | | | |
| 7 | Thidiazuron | 112 | A | X | X | X |
| | Ethephon | 1103 | A | | | |
| 8 | Thidiazuron | 56 | A | X | | |
| | Tribufos | 210 | A | | | |
| 9 | Thidiazuron | 56 | A | X | X | X |
| | Tribufos | 210 | A | | | |
| | Ethephon | 1103 | A | | | |
| 10 | Thidiazuron + Diuron | 26 + 13 | A | X | X | X |
| 11 | Ethephon + Cyclanilide | 1103 + 69 | A | X | X | X |
| 12 | Thidiazuron + Diuron | 18.5 + 9 | A | X | X | X |
| | Ethephon + Cyclanilide | 1103 + 69 | A | | | |
| 13 | Carfentrazone-ethyl[x] | 17.5 | A | X | X | X |
| 14 | Pyraflufen ethyl[x] | 2.7 | A | X | X | X |
| 15 | Paraquat[w] | 560 | A | X | X | X |
| 16 | Thidiazuron | 56 | A | X | X | X |
| | Carfentrazone-ethyl[x] | 17.5 | B | | | |
| 17 | Thidiazuron | 56 | A | X | X | X |
| | Paraquat[w] | 560 | B | | | |
| 18 | Thidiazuron | 112 | A | X | X | X |
| | Tribufos | 315 | A | | | |
| | Ethephon | 1103 | A | | | |
| 19 | Thidiazuron | 56 | A | X | X | X |
| | Thidiazuron + Diuron | 26 + 13 | B | | | |
| 20 | Untreated ($H_2O$) | 0 | A | X | X | X |

[z]Treatments applied at 102.9 L $Ha^{-1}$
[y]Treatments with an 'X' in a year column were included during that growing season
[x] indicates NIS was added at a 0.25% v/v rate
[w] indicates Crop Oil Concentrate was added at a 1% v/v rate
[v]Timings of treatments B were 7 days after application of treatments A

*Data Collection*

**Late Season Measurements**

Prior to harvest aid treatment application, open boll percentage was estimated, and harvest aids were applied at approximately 65% open bolls. Visual ratings to determine the percent defoliation, desiccation, and green leaf were completed at 7 and 14 days after treatment (DAT) from the center two rows of each treatment. These ratings were taken by the same person throughout the entirety of the study. Regrowth was rated for all plots 14 DAT, immediately prior to harvest (Appendix C). Untreated check treatments were rated as 0% defoliated, 0% desiccated, and 100% green leaf and a complete defoliation of the plants within the treatment would be rated as 100% defoliated. The untreated check of each replicate was rated first to provide a baseline for comparison of the percent of defoliation, desiccation, and green leaf.

**Lint Measurements**

Each experimental unit was harvested mechanically with a small plot spindle picker. One of the middle two rows of each plot were harvested in the Coastal Bend counties with a one row International Farmall H cotton picker. The two middle rows of each plot were harvested in the Burleson County trials with a two-row John Deere 9910 cotton picker. Harvested seed cotton was collected in large mesh sacks and stored in a dry location for 1 to 3 weeks prior to processing for yield. Approximately a 500 gram subsample of seed cotton was pulled from the mesh bags for each plot to be ginned.

Seed cotton subsamples were ginned in a microgin which consisted of seed cotton intake, two saw stick machines, an extraction feeder, a ten-saw gin stand, and a single lint cleaner.  This microgin was designed to be representative of the ginning facilities currently in commercial use but on a smaller scale.  Ginned lint samples were delivered to the Texas Tech University Fiber and Biopolymer Institute and the fiber quality parameters were processed using HVI analysis.   Lint quality characteristics quantified by HVI included length, strength, micronaire, brightness, yellowness, color grade and leaf grade.

### *Data Analysis*

In harvest aid efficacy trials, defoliation, desiccation and lint characteristics were analyzed with Statistical Analysis System (SAS) for personal computers, version 9.2 (SAS Institute, 2007).  A Bartlett's test was conducted to confirm homogeneity of variance in defoliation and desiccation levels prior to conducting an analysis of variance test.  The General Linear Model (Proc GLM) was used for the analysis of variance ($P \leq 0.05$).  Protected Fischer's least significant difference at $P \leq 0.05$ was used to separate means.  Using an analysis of variance, data from multiple locations and years were found to have a treatment by location and year interaction for defoliation and desiccation and prevented the combining of data across locations or years (Appendix D.1.).  Leaf grade data were nonparametric and non-normal, and were analyzed with the Kruskal-Wallis test at $\alpha = 0.05$.  The Kruskal-Walis test was developed to handle nonparametric and non-normal data, and was used to determine if defoliation and desiccation affected the leaf grade value within the each location.

## Results and Discussion

### *Harvest Aid Efficacy Trials*

**Burleson County Harvest Aid Efficacy**

Harvest aid treatments showed a site by treatment interaction for defoliation and desiccation between all years and locations as indicated by using analysis of variance ($P \leq 0.05$). Therefore, each site-year will be presented separately. In 2010 the highest percentage of defoliation after 14 DAT was a sequential application of thidiazuron at 56 g AI $ha^{-1}$ (Table 2). A single application of thidiazuron at 28 g AI $ha^{-1}$ at 14 days before harvest provided the lowest level of defoliation at 56%, but was higher than the untreated check. The rates and products were selected to provide a wide range of defoliation levels; however, 45% of the treatments provided greater than 80% defoliation. Harvest aid treatments provided two statistical tiers of desiccation levels, and a range of 20% (Table 2). Paraquat at 560 g AI $ha^{-1}$ provided the highest desiccation rating in 2010 (Table 2). In 2011, 50% of the treatments exceeded a 78% defoliation level. The highest defoliation percentage was a tank mix of thidiazuron at 26 g AI $ha^{-1}$ and diuron at 13 g AI $ha^{-1}$ (Table 2). Paraquat at 32 g AI $ha^{-1}$ provided the lowest defoliation of the evaluated products and the highest levels of desiccation (Table 2).

The cotton in 2012 was over 1.5 meters tall, twice the height as the previous year. Thus reducing spray coverage was reduced by reducing the clearance of the sprayer boom. Only the thidiazuron 56 g AI $ha^{-1}$ followed by the sequential application of thidiazuron + diuron product at 26 + 13 g AI $ha^{-1}$ exceeded the 80% defoliation level (Table 2).

**Table 2.** Plant condition 14 days after application of harvest aid treatments in Burleson County.

| | | | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|---|
| ID | Treatment[z] | g AI $ha^{-1}$ | Timing | Defoliation (%)[y] | Desiccation (%) | Defoliation (%) | Desiccation (%) | Defoliation (%) | Desiccation (%) |
| 1 | Thidiazuron | 56 | A[v] | 96 a | 0 b | 63 cde | 0 a | 79 ab | 4.00 c |
| | Thidiazuron | 56 | B | | | | | | |
| 2 | Thidiazuron | 28 | A | 87 abc | 0 b | 81 abc | 0.2 a | 48 cde | 3.5 c |
| | Ethephon | 2205 | A | | | | | | |
| 3 | Ethephon | 1103 | A | 69 cdef | 0 b | | | | |
| 4 | Thidiazuron | 28 | A | 56 f | 0 b | | | | |
| 5 | Thidiazuron | 112 | A | 79 abcde | 0 b | 56 e | 0 a | 54 bcde | 2.00 c |
| 6 | Thidiazuron | 56 | A | 87 abc | 0.5 b | | | | |
| | Ethephon | 1103 | A | | | | | | |
| 7 | Thidiazuron | 112 | A | 79 abcde | 0 b | 92 a | 0 a | 58 abcde | 4.25 c |
| | Ethephon | 1103 | A | | | | | | |
| 8 | Thidiazuron | 56 | A | 78 abcde | 0.33 b | | | | |
| | Tribufos | 210 | A | | | | | | |
| 9 | Thidiazuron<br>Tribufos<br>Ethephon | 56<br>210<br>1103 | A<br>A<br>A | 87 abc | 0.25 b | 90 ab | 0.5 a | 37 e | 0.33 c |
| 10 | Thidiazuron + Diuron | 26 + 13 | A | 85 abcd | 1.75 b | 95 a | 0.25 a | 78 ab | 7.00 c |
| 11 | Ethephon + Cyclanilide | 1103 + 69 | A | 74 bcdef | 0 b | 61 cde | 0 a | 68 abc | 2.25 c |
| 12 | Thidiazuron + Diuron | 18.5 + 9 | A | 78 abcde | 0 b | 87 ab | 0.25 a | 70 abc | 2.75 c |
| | Ethephon + Cyclanilide | 1103 + 69 | A | | | | | | |
| 13 | Carfentrazone-ethyl[x] | 17.5 | A | 65 f | 0 b | 57 de | 1 a | 54 bcde | 0.75 c |
| 14 | Pyraflufen ethyl[x] | 2.7 | A | 70 cdef | 0.25 b | 71 bcde | 0.25 a | 41 de | 4.2 c |
| 15 | Paraquat[w] | 560 | A | 66 def | 20.5 a | 13 f | 31.67 a | 67 abcd | 15.75 b |
| 16 | Thidiazuron | 56 | A | 83 abcde | 6.25 b | 78 abcd | 0.5 a | 73 abc | 6.25 c |
| | Carfentrazone-ethyl[x] | 17.5 | B | | | | | | |
| 17 | Thidiazuron | 56 | A | 92 ab | 1.6 b | 85 ab | 11.33 a | 63 abcd | 25.00 a |
| | Paraquat[w] | 560 | B | | | | | | |
| 18 | Thidiazuron<br>Tribufos<br>Ethephon | 112<br>315<br>1103 | A<br>A<br>A | 86 abc | 0 b | 90 ab | 0.25 a | 68 abc | 1.25 c |
| 19 | Thidiazuron | 56 | A | 85 abcd | 0.5 b | 89 ab | 6.25 a | 82 a | 15.25 b |
| | Thidiazuron + Diuron | 26 + 13 | B | | | | | | |
| 20 | Untreated ($H_2O$) | 0 | A | 0 g | 0 b | 0 f | 0 a | 0 f | 0 c |
| | | | Pr>F | <0.01 | <0.01 | <0.01 | 0.17 | <0.01 | <0.01 |
| | | | Mean | 75.2 | 1.61 | 70.4 | 2.61 | 58.2 | 5.94 |

[z]Treatments applied at 102.9 L $Ha^{-1}$

[y]Means followed by the same letter in a column, within a specific environment, are not significantly different (P = 0.05).

[x]indicates NIS was added at a 0.25% v/v rate

[w]indicates Crop Oil Concentrate was added at a 1% v/v rate

[v]Timings of treatments B were 7 days after application of treatments A

The least effective treatment only provided 37% defoliation and was a tank mix containing: thidiazuron at 56 g AI $ha^{-1}$, tribufos at 210 g AI $ha^{-1}$ and ethephon at 1102 g AI $ha^{-1}$. Desiccation levels ranged from 0% to 32% with paraquat at 560 g AI $ha^{-1}$ having the highest rating (Table 2)

Each year resulted in a different ranking of treatments and had a significant environment by treatment interaction preventing the combining of data. The differences in the environment confirmed previous findings that plant conditions and local factors required individual field recommendations (Cathey, 1986; Siebert and Stewart, 2006).

**Coastal Bend Harvest aid Efficacy**

Colorado County in 2010 had two treatments that reached 90% defoliation, and the next highest treatment was only 76% defoliation. Plots received rainfall, 1.27 cm, within two hours of initial harvest aid application. The best defoliation was achieved by a sequential of thidiazuron 56 g AI $ha^{-1}$ followed by paraquat at 560 g AI $ha^{-1}$, and a sequential treatment of thidiazuron 56 g AI $ha^{-1}$ followed by thidiazuron + diuron with a rate of 26 + 13 g AI $ha^{-1}$ (Table 3). At 14 DAT, desiccation remained under 5% for all treatments in 2010.

In Matagorda County in 2011, the sequential treatment of thidiazuron 56 g AI $ha^{-1}$ followed by a thidiazuron + diuron product with a rate of 26 + 13 g AI $ha^{-1}$ 7 days later provided the greatest defoliation at 94%. Defoliation levels ranged from 8% to 94%, achieving the goal of the treatment selection for testing leaf grade (Table 3). In 2011, a third of the treatments had defoliation levels of 80% or greater. Paraquat provided a high level of desiccation, 41%, during the 2011 growing season (Table 3).

**Table 3.** Plant condition 14 days after application of harvest aid treatments in Colorado and Matagorda Counties in 2010 to 2012.

| | | | | 2010 (Colorado Co.) | | 2011 (Matagorda Co.) | | 2012 (Colorado Co.) | |
|---|---|---|---|---|---|---|---|---|---|
| ID | Treatment[z] | g AI $ha^{-1}$ | Timing | Defoliation (%)[y] | Desiccation (%) | Defoliation (%) | Desiccation (%) | Defoliation (%) | Desiccation (%) |
| 1 | Thidiazuron | 56 | A[y] | 76 ab | 0.75 d | 76 bc | 0 c | 75 abc | 11.67 b |
| | Thidiazuron | 56 | B | | | | | | |
| 2 | Thidiazuron | 28 | A | 28 fghi | 1.25 d | 78 abc | 0 c | 34 ef | 0 c |
| | Ethephon | 2205 | A | | | | | | |
| 3 | Ethephon | 1103 | A | 5 j | 0.25 d | | | | |
| 4 | Thidiazuron | 28 | A | 39 ef | 1.0 d | | | | |
| 5 | Thidiazuron | 112 | A | 58 dc | 1.25 d | 66 cd | 0 c | 64 bcd | 0.25 c |
| 6 | Thidiazuron | 56 | A | 42 def | 1.5 d | | | | |
| | Ethephon | 1103 | A | | | | | | |
| 7 | Thidiazuron | 112 | A | 38 fg | 1.25 d | 83 abc | 0 c | 69 abcd | 0.25 c |
| | Ethephon | 1103 | A | | | | | | |
| 8 | Thidiazuron | 56 | A | 57 cde | 1.0 d | | | | |
| | Tribufos | 210 | A | | | | | | |
| 9 | Thidiazuron<br>Tribufos<br>Ethephon | 56<br>210<br>1103 | A<br>A<br>A | 35 fg | 1.75 d | 69 dc | 0 c | 75 abc | 0 c |
| 10 | Thidiazuron + Diuron | 26 + 13 | A | 33 fgh | 2.0 cd | 92 ab | 0 c | 74 abc | 0 c |
| 11 | Ethephon + Cyclanilide | 1103 + 69 | A | 21 ghij | 0.5 d | 70 dc | 0 c | 51 cdef | 0 c |
| 12 | Thidiazuron + Diuron | 18.5 + 9 | A | 21 ghij | 1.5 d | 88 ab | 0 c | 59 bcde | 0.5 c |
| | Ethephon + Cyclanilide | 1103 + 69 | A | | | | | | |
| 13 | Carfentrazone-ethyl[x] | 17.5 | A | 16 hij | 4.25 bc | 41 e | 0.75 c | 26 fg | 4.4 bc |
| 14 | Pyraflufen ethyl[x] | 2.7 | A | 13 ij | 5.0 ab | 48 e | 2.0 c | 43 def | 0.4 c |
| 15 | Paraquat[w] | 560 | A | 40 def | 7.0 a | 8 f | 90 a | 52 cdef | 24 a |
| 16 | Thidiazuron | 56 | A | 67 bc | 4.25 bc | 77 bc | 0.25 c | 81 ab | 2 c |
| | Carfentrazone-ethyl[x] | 17.5 | B | | | | | | |
| 17 | Thidiazuron | 56 | A | 90 a | 2.0 cd | 56 de | 40.75 b | 66 abcd | 25 a |
| | Paraquat[w] | 560 | B | | | | | | |
| 18 | Thidiazuron<br>Tribufos<br>Ethephon | 112<br>315<br>1103 | A<br>A<br>A | 43 def | 1.75 d | 87 ab | 0.75 c | 78 abc | 0.75 c |
| 19 | Thidiazuron | 56 | A | 90 a | 1.0 d | 94 a | 1.5 c | 92 a | 1.5 c |
| | Thidiazuron + Diuron | 26 + 13 | B | | | | | | |
| 20 | Untreated ($H_2O$) | 0 | A | 0 j | 0.25 d | 0 f | 0 c | 0 g | 0 c |
| | | | Pr>F | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | | | Mean | 40.5 | 1.98 | 57.9 | 3.94 | 64.9 | 8.5 |

[z]Treatments applied at 102.9 L $Ha^{-1}$

[y]Means followed by the same letter in a column, within a specific environment, are not significantly different (P = 0.05).

[x]indicates NIS was added at a 0.25% v/v rate

[w]indicates Crop Oil Concentrate was added at a 1% v/v rate

[v]Timings of treatments B were 7 days after application of treatments A

Defoliation treatments in 2012 provided a range of 66%, from 26% to 92%. As in 2011, the sequential treatment of thidiazuron 56 g AI $ha^{-1}$ followed by a thidiazuron + diuron product with a rate of 26 + 13 g AI $ha^{-1}$ provided the greatest defoliation (Table 3). A maximum desiccation of 24% by paraquat and the smaller range of desiccation levels were observed in 2011.

The sequential of thidiazuron 56 g AI $ha^{-1}$ followed by a thidiazuron + diuron product with a rate of 26 + 13 g AI $ha^{-1}$ produced greater that 90% defoliation in all three years, and was the best defoliation regime in each year for the Coastal Bend (Table 3). Due to the differences in weather patterns many treatments varied greatly between years, for example thidiazuron + diuron at 26 + 13 g AI $ha^{-1}$ changed from 33% to 92% defoliation, a 59% difference from 2010 to 2011 (Table 3). The variation between years varies from product to product, depending on the environment and the mode of action. Overall a wide range of defoliation and desiccation levels were obtained with the selected defoliation treatments (Table 2 and 3).

## *Cotton Leaf Grade*

### **Defoliation**

Burleson County leaf grade scores were not impacted by the level of defoliation during any of the years of the study. In 2010, the highest leaf grade was observed for several of the treatments exceeding 75% defoliation (Fig. 1). Additionally, the slope was non-significant and thus the leaf grade values cannot be predicted by cotton defoliation levels. Leaf grades in 2011 were the lowest of the three years studied.

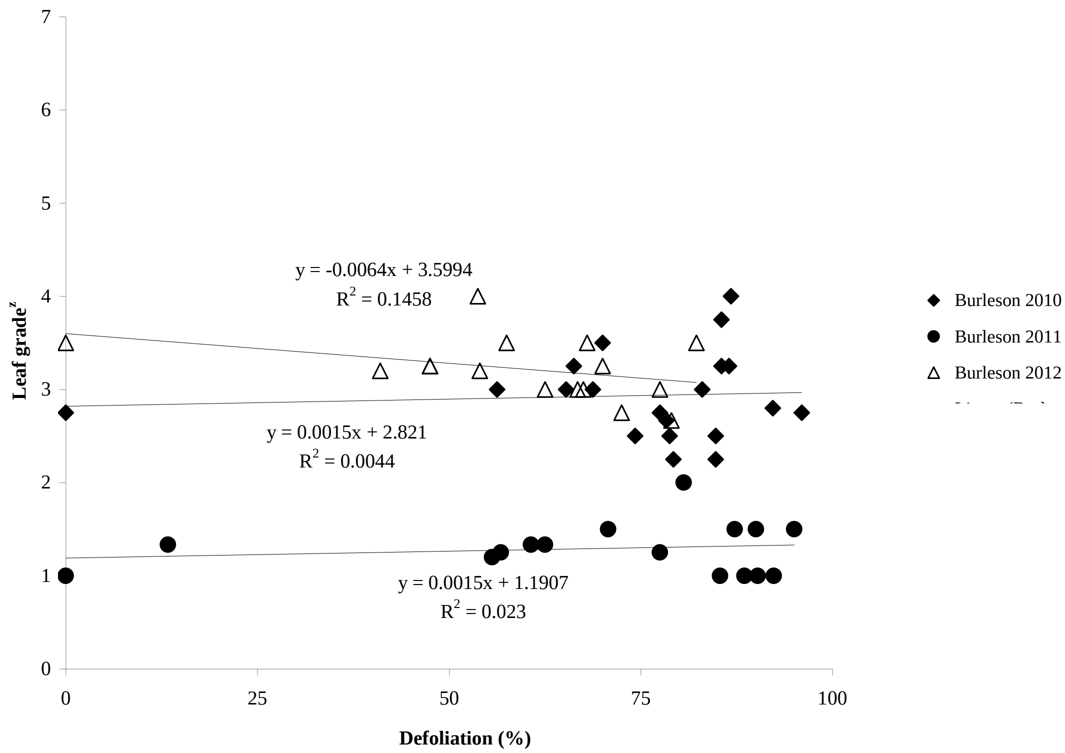



**Figure 1.** Leaf grade of cotton as impacted by percent leaf defoliation of different harvest aid regimes over three years at the TAES Research Farm in Burleson County, 2010-2012. [z]Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the defoliation level in any year (P = 0.05). All trendlines were found to be non-significant.

In 2010 and 2012, leaf grade scores reached the range of 3 and 4, while in 2011 leaf grade values did not rise above 2 (Fig. 1). Lower leaf scores in 2011 were likely the result of conditions more suitable for harvest, compared to Burleson County in 2010 and 2012.

Coastal Bend leaf grade values were not impacted by the level of leaf defoliation achieved by the various harvest aid treatments (Fig. 2). Defoliation levels were evenly distributed between the minimum and maximum. In 2010 in Colorado County, leaf grade values of 4 or greater were observed in over half of the treatments. Cotton at this location was 1.5 m tall, and had a large canopy, which made harvest aid application, as well as the harvesting process; difficult high temperatures and low rainfall were experienced in 2011 across the region, making harvest conditions better suited for lower leaf grade scores. In all site-years, defoliation accounted for a small amount of the variance in leaf grade scores; the best fitting trend was Colorado County in 2010, with only a $R^2$ value of 0.2.

**Desiccation**

Burleson County trials had minimal desiccation in the 2010 growing season. In 2011 and 2012, desiccation increased for several treatments. Leaf grade was not influenced by the amount of desiccation in any year (Fig. 3). No significant regression of desiccation and leaf grade was found for any environments (Fig. 3 and 4). The highest leaf grade achieved in Burleson County had 0% desiccation.

Desiccation in the Coastal Bend region varied greatly between years (Fig. 4).

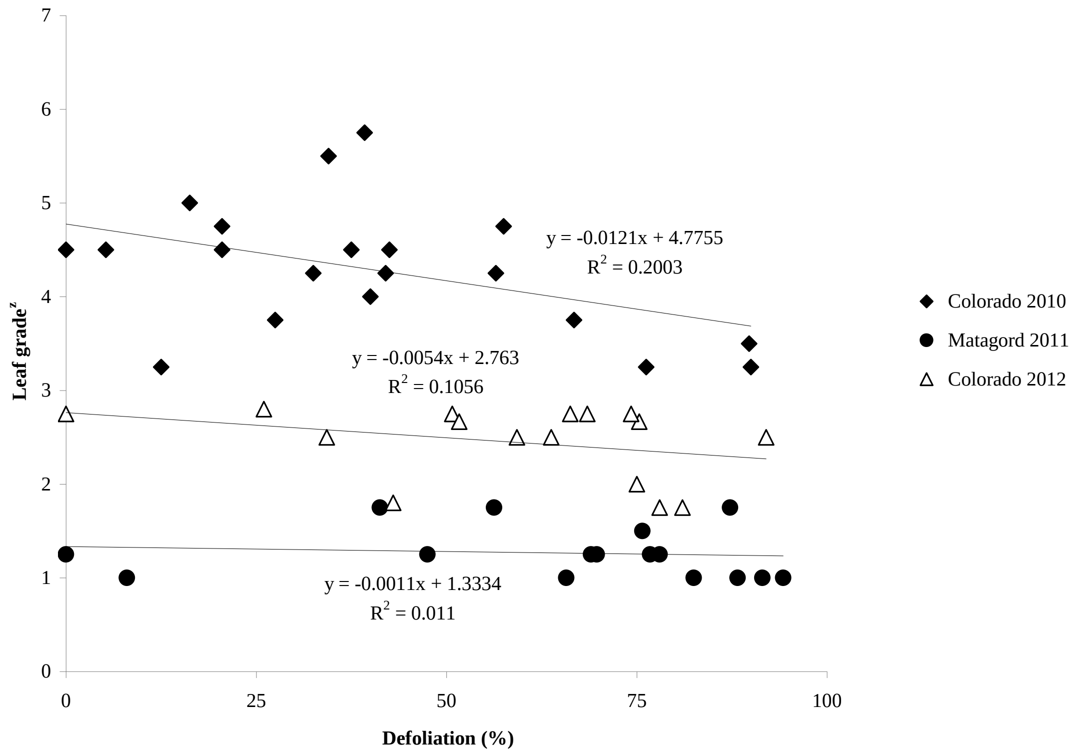



**Figure 2.** Leaf grade of cotton as impacted by percent leaf defoliation of different harvest aid regimes over three years located in Colorado County in 2010 and 2012, and Matagorda County in 2011. [z]Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the defoliation level in any year (*P* = 0.05). All trendlines were found to be non-significant.

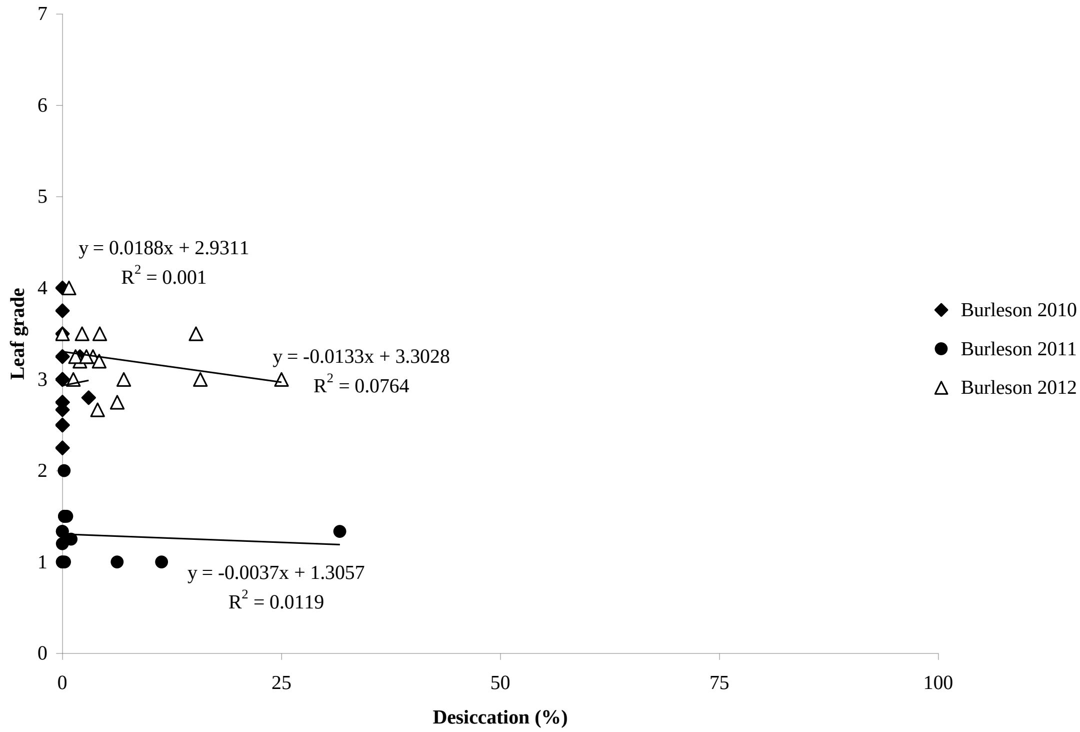



**Figure 3.** Leaf grade of cotton as impacted by percent leaf desiccation of different harvest aid regimes over three years located in Burleson County in 2010-2012. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the desiccation level in any year (P = 0.05). All trendlines were found to be non-significant.

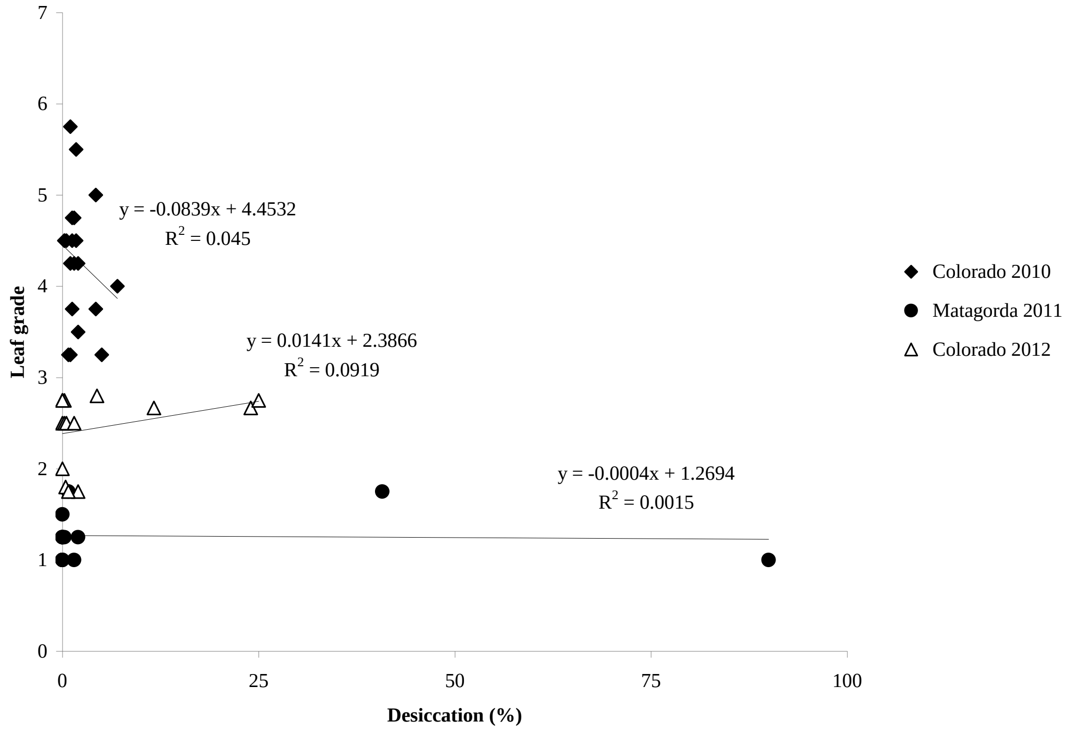



**Figure 4.** Leaf grade of cotton as impacted by percent leaf defoliation of different harvest aid regimes over three years located in Colorado County in 2010 and 2012, and Matagorda County in 2011. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the desiccation level in any year (P = 0.05). All trendlines were found to be non-significant.

The highest level of desiccation of any environment was produced by paraquat in 2011 (Fig 3 and 4). However, despite 90% desiccation, a leaf grade rating of one was assigned to the ginned lint. Leaf grade was not affected by the desiccation level at any of the six different environments.

## Conclusions

The wide range of defoliation and desiccation levels were achieved with the selected harvest aid treatments. Valco and Snipes (2001) analyzed 16 separate test sites and seven harvest aid treatments, and found only minimal reductions in measurements of trash. The results of this study indicated that the leaf grade of ginned cotton lint is not directly impacted by the level of defoliation, which is consistent with Beltwide data previously collected (Valco and Snipes, 2001). Furthermore, the level of desiccation does not have a direct impact on cotton leaf grade either. However, environmental factors throughout the duration of this study prevented the combining of data, which included an abnormally high percentage of leaf grade scores of 1 and 2 in 2011 throughout the region (USDA, 2012). The differences in environment, which includes, plant condition, application conditions, and weather, were found to have consistent influences on the effectiveness of harvest aid treatments. This coincides with previous studies finding timing, canopy density, translocation of chemicals, and varietal traits can influence defoliation and desiccation (Cathey, 1986; Oosterhuis et al., 1991). Variation between years was found within individual treatments, as well as stability between years, for a select few treatments. The unpredictable trend between years and locations reinforces the practice of field by field harvest aid recommendations. Observed conditions in 2011, extreme heat and drought, proved to be best suited for achieving low leaf grades out of the three years of trials. Ultimately, there were no individual treatments that provided a better leaf grade consistently over multiple years or environments.

CHAPTER III

# COTTON CULTIVAR CHARACTERISTICS AND THEIR IMPACT ON COTTON LEAF GRADE

## Overview

The remnants of leaf material in harvested cotton, *Gossypium hirsutum* L., can significantly increase leaf grade values, and result in discounts to the producer and increase ginning cost to ginners. Cotton classed through the USDA-AMS Classing Office in Corpus Christi, Texas has reported increases in leaf grade values beginning in 2000 (USDA, 2012). The impacts of the agronomic characteristics of cotton cultivars were studied over two growing seasons and data were used to narrow possible contributors to increased leaf grade values. Multiple trials were conducted in five counties in Texas, including the Lower and Upper Coastal Bend and the Blackland Prairie, and were defoliated with a uniform harvest aid treatment to identify leaf and bract pubescence differences, leaf and bract area and the resulting impact on cotton leaf grade values. Multi-acre module trials were also conducted to compare leaf grade values of a smooth leaf cultivar (DP 0935B2RF) and a hairy leaf cultivar (DP 0949B2RF) when processed through a commercial gin. Visual quantification of leaf and bract pubescence was conducted on the youngest fully-expanded leaf and mid-canopy bracts, respectively, when cotton was at physiological cut-out. A total of 5 to 10 leaf and 5 to 10 bract samples were collected and quantified for all cultivars. Results from pubescence quantification indicated substantial variation in cultivars and discrepancies from company based rating systems. All samples were transported and ginned in a microgin at the Texas A&M University AgriLife Research Center in Lubbock. Leaf grades values from these trials demonstrated that increased leaf trichome density increases the propensity for higher leaf grade values. Leaf trichome densities did not consistently agree with company leaf hairiness ratings. In all years, and locations, semi-smooth Phytogen 499WRF was found to have as dense, or denser, trichomes as all hairy rated cultivars.

## Introduction

Harvesting cotton, *Gossypium hirsutum* L., is an ever changing process that is commonly referred to as more art than a science by industry leaders to maintain cotton fiber quality (Supak and Snipes, 2001). Cotton leaf contamination, categorized as cotton leaf grade by a cotton classing office and based on a standard rating system, is one fiber quality characteristic that can be improved by increased lint cleaning and the ginning process. However, in the past decade, cotton leaf grade values have increased for cotton lint grown along the Gulf Coast of Texas and have resulted in decreased profits for producers and ginners (Appendix A). Cotton leaf grade is the visual estimate of the quantity of leaf and bract material in a lint sample following ginning, on a scale of 1 to 7, with 1 being a lowest leaf contamination value. As the plant material, leaf and bract, increases, more lint cleaning is required during the ginning processes to minimize discounts from higher leaf grade values. However, increased lint cleaning can lead to increased fiber breakage and fiber length price discounts (Faulkner et al. 2008; Sui et al., 2010). If plant materials cannot be removed during the ginning process, higher leaf grade values will result in discount prices to producers, which generally begin at leaf grade values of four and increase as leaf grade values increase. Either of these options will result in reduced income to the producer.

Several agronomic factors are believed to negatively influence the leaf grade values, including: cotton defoliation, late-season weather conditions, and some cotton cultivar characteristics (Anthony and Rayburn, 1989; Morey et al. 1976). Reducing the amount of plant material (leaf, bract, petiole, etc.) flowing through the harvester, into the cotton module, and through the ginning process is an important step in improving fiber quality (Sui et al., 2010). The majority of all foreign materials found in lint are components of leaf and bracts (Sui et al. 2010). As the leaf grade increases, more lint cleaning is required in the ginning process to remove these plant materials. From the miller's perspective, these plant materials entangle in the lint and decrease the yarn and fabric quality. Excessive cleaning of the lint can slow production and lead to fiber breakage, and result in decreased the short fiber content and increase the lint waste (Sui et al. 2010).

Cotton cultivars can be distinctive from one another in terms of leaf size, hairiness, and growth habits, and can detrimentally impact cotton leaf grade (Novick et al. 1991; Smith, 1964). Leaf grade values of the ginned lint can be impacted by the pubescence, or hairiness, of the cotton cultivar, which is determined by the presence and density of trichomes (Anthony and Rayburn, 1989; Rayburn, 1988; Rayburn and Libous, 1983). Trichomes are hair-like protrusions on the surface of the various plant parts including leaves, bracts, petioles, and stems (Bradow and Wartelle, 1998; Oosterhuis and Jernstedt, 1999). Cotton trichomes on leaves, leaf margins and stems are genetically controlled by multiple alleles at five loci (Percy and Kohel, 1999). Some of these alleles can affect different plant tissues and organs. Trichome densities between different regions of the leaf have strong positive correlations, including the petiole, mid-vein, blade and margins (Smith, 1964).

Bracts are modified leaves that surround the developing flower bud and boll on the cotton plant. Cotton bracts have been reported to be a major contributor to leaf trash in harvested lint (Morey et al. 1976). For this reason, alteration of the bract physiology has been attempted in the past by plant breeders. However, bract size reduction or reducing their persistence has shown to negatively impact the overall plant physiology and can be highly influenced by environmental factors, such as drought (Bourland and Hornbeck, 2007; Wullschelger et al., 1990; Zhao and Oosterhuis, 2000).

Trichome density influences the efficiency and efficacy of the lint cleaning process through ginning (Rayburn 1988). Lint from smooth leaf cultivars is easier to clean and thus lower leaf grade values can be accomplished (Rayburn and Libious, 1983; Anthony and Rayburn, 1989). Trichomes do serve various positive uses for the plant, including reducing transpiration, and protecting from herbivorous insects (Bourland and Hornbeck, 2007; Wullschelger et al., 1990; Zhao and Oosterhuis, 2000). Leaf trichome density also has other implications on cotton management. Mekala (2013) reported cotton fleahoppers density increased with increasing trichome density. However, Jenkins and Wilson (1996) and Norman and Sparks (1997) reported increased susceptibility to whiteflies for cotton cultivars with more dense leaf trichome levels, and an increased need for insecticide applications to manage whiteflies (Norman and Sparks, 1997).

Current universal industry standards for leaf trichome density ratings do not exist, and all ratings are subject to a company's proprietary process and scale as leaf hairiness. Norman and Sparks (1997) found that while some cultivars maintained stable trichome densities over multiple years, many have wide variations across years. Standard trichome ratings have been proposed by various sources, but none have been fully adopted by the cotton industry (Bourland and Hornbeck, 2007; Smith, 1964; Rayburn, 1986). Smith (1964) evaluated cotton trichomes grown in Alabama and found a range of 2 to 205 trichomes $cm^{-2}$, where a Deltapine Smooth Leaf cultivar was viewed as the standard for the smooth leaf cultivar in his ratings. To study cotton hairiness, Rayburn (1986) separated cultivars into smooth and hairy categories, prior to the development and commercial release of reduced hairy cultivars that were an intermediate in hairiness. Rayburn (1986) quantified leaf trichomes, and proposed a three class system of "smooth", "moderately hairy", and "hairy". Bourland et al. (2003) noted that following this study the release and classification of multiple cultivars as "reduced hair" became available to Delta producers as "semi-smooth" cultivars. The most objective rating method published is the quantification of the trichomes proposed by Bourland et al. (2003), where trichome density is quantified at the base of the leaf on the abaxial side. However, quantification of leaf trichome densities has not been adopted by the industry, in part, due to the time required to quantify the trichome density. Bourland et al. (2003) developed a visual rating system for leaf hairiness (1-9) based on abaxial leaf trichome density. Bourland and Hornbeck (2007) proposed another method that increased the efficiency of leaf hairiness ratings, but their methodology was subjective and has not been widely adopted.

Variation between seasons has been found, as well as variation within a single plant, depending on the location within the canopy (Bourland et al., 2003). Bourland et al. (2003) collected leaf samples from three regions of the plant and compared trichome densities. The trichome density decreased as leaves matured and may be attributed to the physical wearing off of the trichomes. Therefore, Bourland et al. (2003) identified the leaves five nodes from the apex, first fully expanded leaf, as the most representative leaf of the plant's leaf trichome density. Additional testing on marginal bract trichome density found that mid-canopy, first position bolls were the best representation of bract trichomes (Bourland and Hornbeck, 2007; Hornbeck and Bourland, 2007). The relationship between bract trichome density and leaf trichome density were significantly correlated in studied cultivars, with values of 0.35 and 0.33 in 2001 and 2002, respectively, within a segregating $F_2$ population (Hornbeck and Bourland, 2007).

### *Objectives*

The objectives of this research trial were to analyze the impact of leaf size, bract size, leaf trichome density, bract marginal trichome density and other morphological traits on cotton leaf grade value. A secondary objective was to verify the accuracy of industry leaf hairiness ratings with trichome density.

## Materials and Methods

### *Cultural Practices*

Comparisons of cultivar characteristics and their impact on leaf grade were conducted from 2011 to 2012 in multiple locations including: Tifton, Georgia; Lower Coastal Bend of Texas; the Upper Coastal Bend of Texas; and the Texas Blackland Prairie. Lower Coastal Bend counties were Nueces County in 2011, and San Patricio in 2012. Upper Coastal Bend data were collected in Matagorda County in 2011 and 2012. Williamson County was the location within the Texas Blackland Prairie in 2011 and 2012. In 2012, Tifton GA was an added as a location to represent the Southeastern Cotton Belt. Soil types for the cultivar trials were a Victoria clay (fine, smectitic, hyperthermic sodic haplusterts) in Nueces in 2011, a Raymondville clay loam (fine, mixed, superactive, hyperthermic vertic calciustolls) in San Patricio in 2012, a Laewest clay (fine, smectitic, hyperthermic typic hapluderts) in the Matagorda County during 2011 and 2012, a Branyon clay (fine, smectitic, thermic udic haplusterts) in Williamson County during 2011 and 2012, and a Tifton loamy sand (fine-loamy, kaolinitic, thermic plinthic kandiudults) in Tifton, Georgia in 2012. These trials were managed according to Texas A&M AgriLife Extension recommendations.

In two separate studies in 2011 and 2012, cultivar comparison trials were conducted as field scale module trials in Wharton and Williamson Counties. Soil types for these locations were a Lake Charles clay (fine, smectitic, hyperthermic typic hapluderts) in Wharton County 2011, an Edna-Cieno complex of Edna (fine, smectitic, hyperthermic aquertic chromic hapludalfs) and Cieno (fine-loamy, siliceous, active, hyperthermic typic vermaqualfs) in Wharton in 2012, a Krum silty clay (fine, smectitic, thermic udertic haplustolls) in Williamson County in 2011 and a Branyon clay (fine, smectitic, thermic udic haplusterts) in Williamson County during 2012. Cotton was planted, managed, and harvested by local producers implementing recommended practices of the Texas A&M AgriLife Extension Service. Precipitation and temperatures for each location are reported in Appendix B.

*Cultivar Trials*

Cultivars from the Replicated Agronomic Cotton Evaluation (RACE) trials were selected to provide a range of leaf hairiness, smooth to hairy, based on the cultivar descriptions provided by seed companies. RACE trial plot dimensions ranged from 1.23 to 1.73 hectares in size. All cultivars were defoliated and harvested under the local commercial harvesting practices. Each location had a minimum of 85% defoliation when the trials were harvested treatments. A six kg sub-sample was collected from each plot from the basket of the cotton weigh wagon to be ginned and lint analysis with HVI be conducted, including cotton leaf grade.

*Module Trials*

Module trials were conducted in Williamson and Wharton Counties during the 2011 and 2012 growing season. Deltapine 0935B2RF (DP 0935B2RF), a smooth leaf cultivar and Deltapine 0949B2RF (DP 0949B2RF), a light hairy cultivar, were grown in a randomized complete block design. Plot size consisted of twelve-row strips of a cultivar across an entire length of the field in an alternating pattern. Based on average yields for these regions, four modules for each cultivar should have been obtained.

Cotton in Wharton County was harvested with two four-row cotton spindle pickers, and cultivars were deposited in separate modules in 2011. Due to below normal precipitation, three complete modules were obtained for each cultivar. In 2012, four modules were obtained from each cultivar. Williamson county module trials were harvested using a cotton stripper harvester. In 2011, one module from each cultivar was completed due to extremely low yields. In 2012, three modules were obtained. Each module was considered a replicate, and all bales within the module were treated as subsamples. The modules were covered and processed using normal module handling and ginning techniques for the local area. Cotton from the Wharton and Williamson Counties were classed using HVI analysis at the Corpus Christi and Abilene USDA Classing Office, respectfully. Lint analyses were obtained from the commercial gin for each bale within each module.

*Morphological Data Collection*

**Leaf Sampling**

Morphological data were collected for all the trials in 2011 and 2012 and included leaf trichome density, bract trichome density, leaf area, bract area, and bract length. When the cotton plants were near physiological cutout at each location, five nodes above white flower, leaf and bract samples were collected. In 2011, five leaves and five bolls were sampled from each location. However, after evaluating the 2011 data, ten leaves and ten bolls were sampled in 2012. The first fully expanded leaves were selected from five nodes from the apex of the plant as described by Bourland et al. (2003). Bract samples were collected from a full-size, first position boll near the middle of the plant as described by Bourland and Hornbeck (2007). One bract was removed from the base of each of the sampled bolls. For leaves and bracts, the samples were placed in a cooler at approximately 10 degrees C in the field and were transferred to a refrigerator set at 4 degrees C until trichomes were quantified for each cultivar and location. Leaf and bract area was calculated using a Li-Cor 3100 leaf area meter (LI-COR Inc., Lincoln, NE).

An index card with a 0.65 cm diameter hole (0.33cm$^2$) was laid over the interveinal area near the base of the leaf of the abaxial side of the leaf and leaf trichome densities were quantified. On opposite sides of the bract, the mean value for two margin areas of the center tooth were quantify for 0.65 cm length. Trichomes were quantified using a dissecting microscope with an alternative light source. Methods described above were described by Bourland et al. (2003), Bourland and Hornbeck (2007), and Hornbeck and Bourland (2007).

**Lint Measurements**

Seed cotton samples from the cultivar trials were ginned in a microgin consisting of seed cotton intake, two saw stick machines, an extraction feeder, a ten-saw gin stand, and single lint cleaner. This microgin was designed to be representative of commercial ginning facilities, but on a smaller scale. Following ginning, lint samples were submitted to and processed by the Fiber and Biopolymer Research Institute at Texas Tech University using HVI analysis. Lint characteristics data gathered included: length, strength, micronaire, brightness, yellowness, color grade and leaf grade.

### *Data Analysis*

In cultivar and module trials, leaf characteristics were analyzed with Statistical Analysis System (SAS), version 9.2 (SAS Institute 2007). A Bartlett's test was conducted to confirm homogeneity of variance prior to conducting an analysis of variance test. The General Linear Model (Proc GLM) was used for the analysis of variance ($P \leq 0.05$). A Protected Fischer's least significant difference test at $P = 0.05$ was used to separate means. Data from multiple locations and years were found to have a cultivar by environment interaction for leaf trichomes, bract trichomes, and leaf and bract size preventing the combining of data. The Kruskal-Wallis test, used to analyze nonparametric leaf grade data, at $\alpha$=0.05 was used to determine if leaf and bract traits affected the score of leaf grade for individual environments, because of the environmental interactions. Pearson correlations and Spearman correlations, for nonparametric data, were conducted to determine interactions between morphological variables and leaf grade.

## Results and Discussion

### *Cultivar Trials*

Similar to previous research findings, inconsistencies in the measured physiological characteristics was observed in this trial. A significant cultivar by environment interaction for leaf trichomes, bract trichomes, and leaf size was observed as indicated by using analysis of variance ($P \leq 0.05$) (Appendix D.3.). Inconsistencies among environments were documented by previous research and cultivars were not the same in each location or year which further decreased the opportunity to compile the data across locations or years.  Therefore, each site will be presented separately.

Cotton cultivars grown in Nueces County in 2011 consisted of two smooth leaf, three semi-smooth leaf, and one hairy leaf cultivar according to their respective company leaf hairiness rating.  Based on LSD separations, three categories of leaf trichome density were observed at this location, including, less than 50 trichomes $cm^{-2}$, 200 to 244 trichomes $cm^{-2}$, and above 345 trichomes $cm^{-2}$ (Table 4).  The cultivars with trichome densities less than 245 trichome $cm^{-2}$ matched the company descriptions of smooth and semi-smooth.  However, Phytogen 499WRF (PHY 499WRF) was labeled by the company as a semi-smooth cultivar and had a higher trichome density than Stoneville 5458B2RF (ST 5458B2RF) cultivar with a company label of hairy.  Bract trichome density followed a similar numerical trend to the leaf trichome density, but no statistical differences were observed.  Differences in bract area were observed with PHY 499WRF and Deltapine 1032B2RF (DP 1032B2RF) having the largest bract size and leaf size.  Bract trichome density, leaf area, and bract length were not different ($P \leq 0.05$) between any of the cultivars (Table 4).  Leaf grade values reported from commercial lint samples processed by the Corpus Christi Classing office were below normal in 2011 (Appendix A).  Similarly low leaf grade values were observed in this trial in Nueces County trial and no samples exceed a leaf grade value of two.  Leaf grade values were not impacted by any of the cultivars, trichome density, or bract area (Fig. 5).

In 2012, San Patricio County cultivars included one hairy, one smooth, and five semi-smooth cultivars according to company ratings.  The highest densities of leaf and bract trichomes were found on two cultivars classified as semi-smooth cultivars by the companies, PHY 499WRF and Americot 1511B2RF (AM 1511B2RF) (Table 5). However, both PHY 499WRF and AM 1511B2RF trichomes were more dense than ST 5458B2RF by greater than 118 trichomes $cm^{-2}$ which is classified as a hairy cultivar by the company. Fibermax 1944GLB2 (FM 1944GLB2) represented the smooth leaf category with less than 9 leaf trichomes $cm^{-2}$. PHY 499WRF and AM 1511B2RF had higher numerical bract trichome densities but was statistically different than the other cultivars.

Leaf area, bract area and length were not different between cultivars (Table 5). Conditions at harvest were extremely dry, with temperatures near 38 degrees C, and likely contributed to low leaf grade values (Appendix A and B). FM 1944GLB2 had the lowest trichome density, and the lowest numerical leaf grade value. AM 1511B2RF had the second most dense level of leaf trichomes, but there was a significant correlation between trichome density and leaf grade in 2012 (Fig. 6; Appendix E.2.).

Cultivars were grown in Matagorda County in 2011 and 2012 to represent the Upper Coastal Bend of Texas. Due to interactions of locations and years and some differences in cultivars evaluated, Matagorda was not analyzed with the Lower Coastal Bend locations. Despite the interactions, similar rankings were observed in measured rankings between Matagorda, San Patricio, and Nueces counties. PHY 499WRF had the highest density of leaf trichomes, while ST 5458B2RF had the highest numerical density of bract trichomes. Leaf trichomes had a range of 234 trichomes $cm^{-2}$ between cultivars of company rated semi-smooth cotton, PHY 499WRF and PHY 367WRF (Table 6).

**Table 4.** Analysis of leaf and bract characteristics of cultivars grown in Nueces County trials in 2011.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 395.8 a[y] | 37.6 a | 99.5 a | 6.42 a | 4.20 a |
| ST 5458B2RF | Hairy | 344.8 a | 28.0 a | 84.3 a | 5.00 b | 3.62 a |
| PHY 367WRF | Semi-Smooth | 243.7 b | 26.6 a | 91.6 a | 5.17 b | 3.59 a |
| DP 1044B2RF | Semi-Smooth | 199.3 b | 22.2 a | 87.6 a | 4.74 b | 3.29 a |
| FM 1740B2F | Smooth | 49.0 c | 24.2 a | 87.5 a | 5.67 ab | 3.80 a |
| DP 1032B2RF | Smooth | 11.9 c | 27.3 a | 91.8 a | 6.51 a | 4.11 a |
| Pr>F | | <0.01 | 0.27 | 0.18 | 0.02 | 0.32 |
| %CV | | 16.5 | 27.2 | 7.31 | 10.4 | 13.6 |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

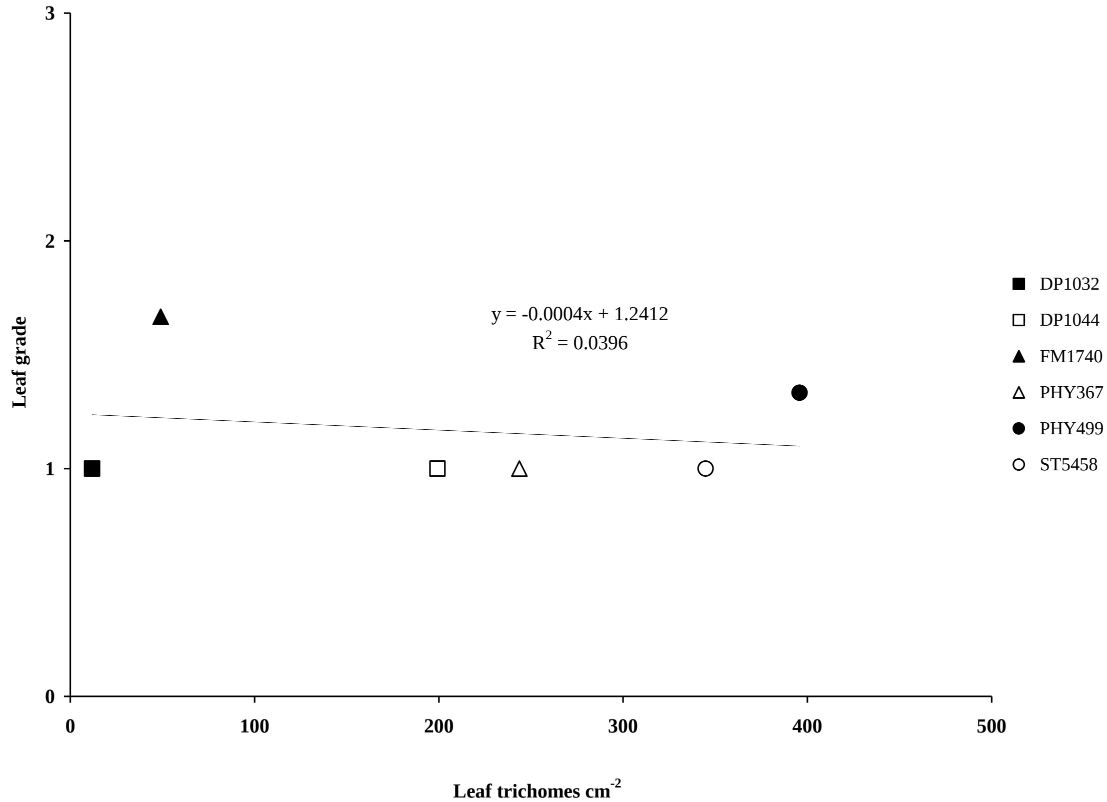



**Figure 5.** Leaf grade as impacted by the density of trichomes on different cultivars[z] grown in Nueces County in 2011. Each value for the respective cultivars was averaged over all replications in this trial. Spearman correlation and Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the trichome density level in this trial ($P$ = 0.05). [z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

**Table 5.** Analysis of variance for leaf and bract characteristics of cultivars grown in San Patricio County, 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 393.6 a[y] | 37.6 a | 80.2 a | 7.39 a | 4.48 a |
| AM 1511B2RF | Semi-Smooth | 362.8 a | 36.6 a | 75.0 a | 6.45 a | 4.92 a |
| ST 5458B2RF | Hairy | 244.7 b | 32.5 a | 77.7 a | 6.91 a | 4.52 a |
| PHY 367WRF | Semi-Smooth | 180.9 b | 34.8 a | 76.5 a | 6.69 a | 4.44 a |
| PHY 375WRF | Semi-Smooth | 188.7 b | 29.9 a | 77.1 a | 6.76 a | 4.47 a |
| DP 1044B2RF | Semi-Smooth | 182.4 b | 28.5 a | 66.7 a | 6.6 a | 4.36 a |
| FM 1944B2F | Smooth | 8.84 c | 28.5 a | 85.8 a | 7.07 a | 4.52 a |
| Pr>F | | <0.01 | 0.27 | 0.09 | 0.51 | 0.07 |
| %CV | | 45.2 | 16.6 | 8.23 | 8.34 | 4.25 |

[z]Americot (AM), Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

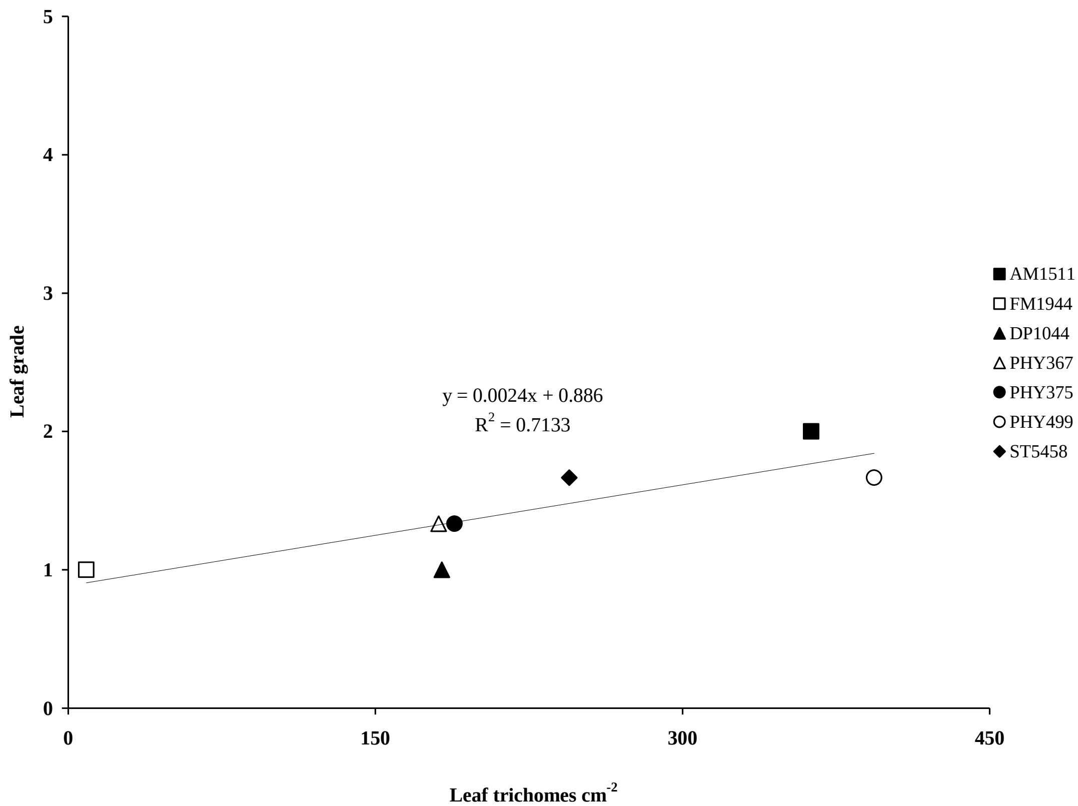



**Figure 6.** Leaf grade as impacted by the density of trichomes on different cultivars[z] grown in San Patricio County in 2012. Each value for the respective cultivars was averaged over all replications in this trial. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the trichome density level in this trial ($P$ = 0.05). [z]Americot (AM), Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

**Table 6.** Analysis of leaf and bract characteristics of cultivars grown in Matagorda County trial in 2011.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 371.1 a[y] | 35.0 ab | 120.1 a | 6.80 a | 4.91 a |
| ST 5458B2RF | Hairy | 282.2 b | 36.2 a | 127.1 a | 5.82 bc | 4.91 a |
| DP 1044B2RF | Semi-Smooth | 145.7 c | 31.5 ab | 106.2 a | 5.03 c | 4.47 a |
| PHY 367WRF | Semi-Smooth | 136.8 c | 32.9 ab | 99.2 a | 5.01 c | 4.82 a |
| FM 1740B2F | Smooth | 35.0 d | 29.6 bc | 115.4 a | 5.67 bc | 4.80 a |
| DP 1032B2RF | Smooth | 38.9 d | 25.0 c | 123.5 a | 6.26 ab | 5.12 a |
| P>F | | <0.01 | 0.3 | 0.24 | 0.01 | 0.19 |
| %CV | | 17.9 | 11.2 | 12.6 | 8.91 | 5.7 |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

Smooth leaf cotton cultivars, Fibermax 1740B2F (FM1740B2F) and DP 1032B2RF, were roughly 100 trichomes $cm^{-2}$ less than the PHY 367WRF and all were listed as semi-smooth cultivars (Table 6). Bract trichome densities had a range of 11 trichomes $cm^{-1}$, and followed a similar trend to leaf trichome densities. The two cultivars with the lowest leaf trichome densities also had the lowest bract trichome densities, including DP 1032B2RF and FM 1740B2RF (Table 6).

Sufficient moisture resulted in large cotton and abundant plant growth. Leaf sizes for all cultivars, except PHY 367WRF, were greater than 100 $cm^2$ (Table 6). Bract areas were greater than 5 $cm^2$ for all cultivars, and PHY 499WRF had the largest bract mean size. However, no differences were observed in the leaf area or bract length. Matagorda had significant positive correlation in 2011 of increasing trichome density increasing leaf grade values despite a narrow leaf grade value range between 1 to 2 (Fig. 7). PHY 499WRF was the hairiest cultivar in this trial, and had the highest leaf grade value (Fig. 7). The two hairiest cultivars exhibited a one leaf grade rating increase over the two smoothest cultivars (Fig. 7).

Leaf grades values in 2012 were similar to the historical average of leaf grade values of 3 reported by the Corpus Christi classing office (USDA, 2012). Matagorda 2012 leaf grade values ranged from 1 to 4 (Fig. 8). As with the previous year, there was a significant positive correlation of increasing trichome density and increasing leaf grade (Appendix E.3 and 4.). PHY 499WRF and ST 5458B2F had the highest density of leaf trichomes, over 300 trichomes $cm^{-2}$, and exhibited triple the leaf grade values of the low trichome density cultivars (Fig. 8).

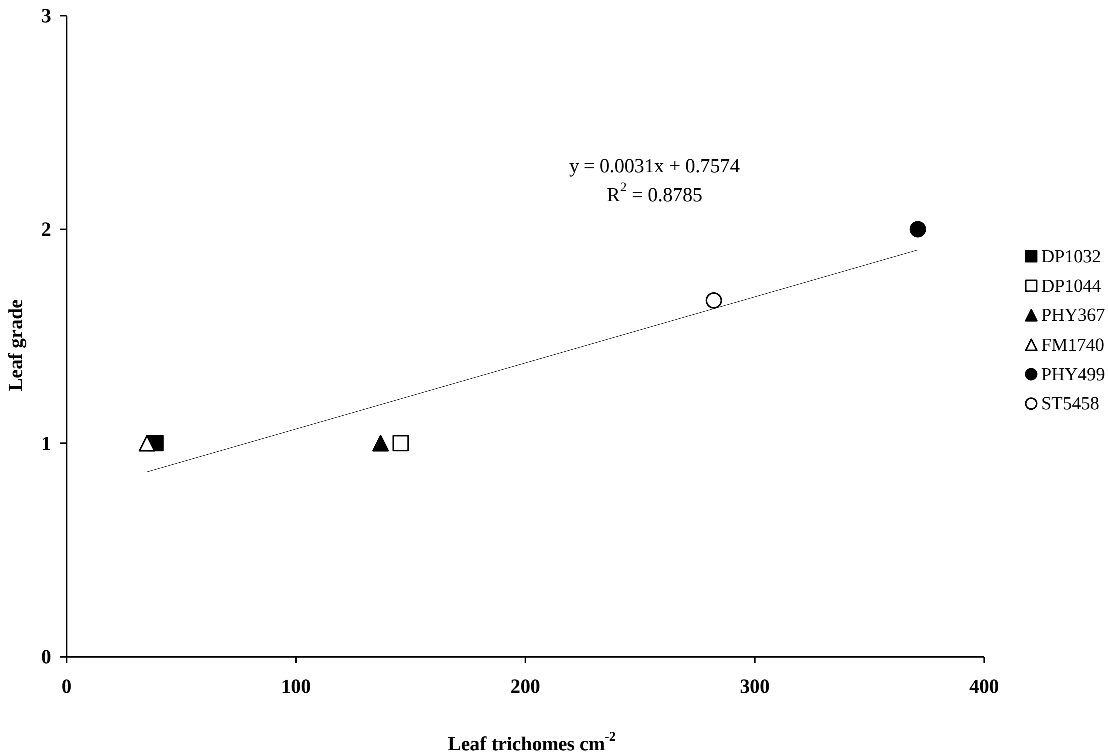



**Figure 7.** Leaf grade as impacted by the density of trichomes on different cultivars[z] grown in Matagorda County in 2011. Each value for the respective cultivars was averaged over all replications in this trial. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the trichome density level in this trial ($P = 0.05$).
[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

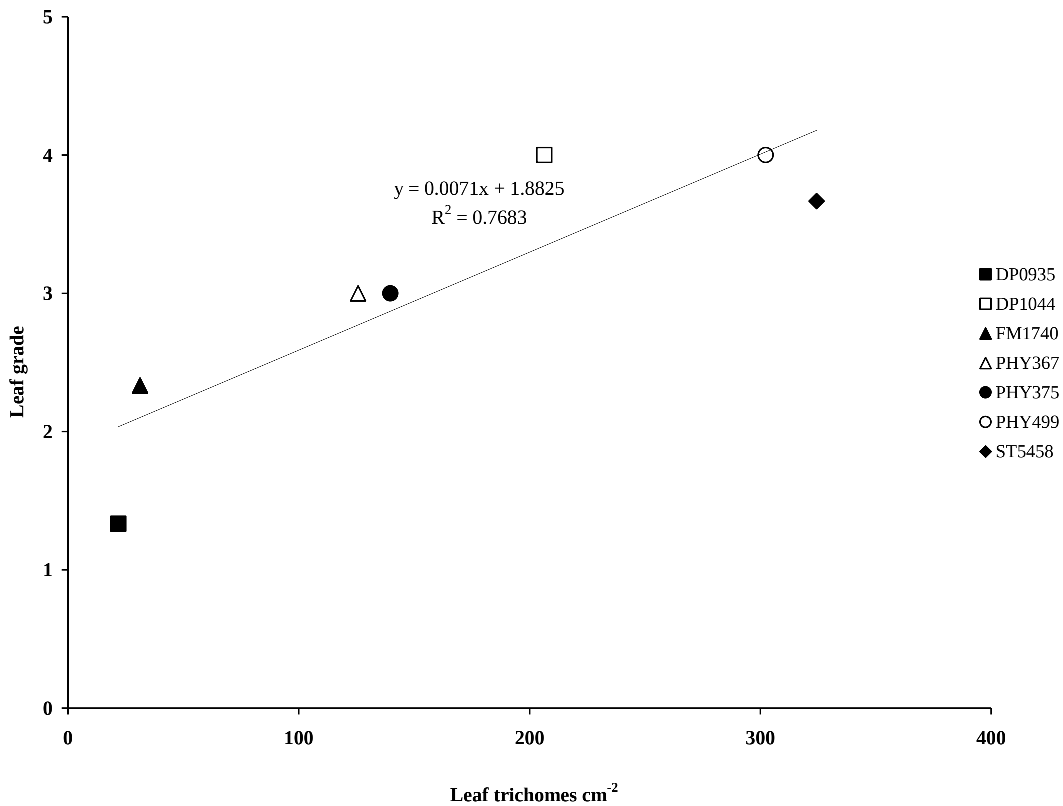



**Figure 8.** Leaf grade as impacted by the density of trichomes on different cultivars[z] grown in Matagorda County in 2012. Each value for the respective cultivars was averaged over all replications in this trial. Kruskal-Wallis test indicated the cotton leaf grade was influenced by the trichome density level in this trial (*P* = 0.05). [z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

Since the established cotton cultivar trials were used for these studies, some dissimilar cultivars were grown in Matagorda in 2012, but five cultivars were the same over both years. Most cultivar trichome densities were stable from year to year in the Matagorda environment, staying within 10% of each year, which is useful in determining rankings for different cultivars. PHY 367WRF, in 2011, had 136.8 trichomes $cm^{-2}$, and in 2012 had 125.7 trichomes $cm^{-2}$ (Table 7). Only three cultivars were greater than PHY 367WRF in both years of the study (Table 6 and 7).

Some stability in leaf trichome density existed across years for FM 1740B2F, a smooth leaf cultivar that had 35 trichomes $cm^{-2}$ in 2011 and 31 trichomes $cm^{-2}$ in 2012 (Table 6 and 7). ST 5458B2RF and PHY 499WRF had the highest density, and the seven cultivars at this location had a range of over 300 trichomes $cm^{-2}$. Bract trichome densities were very similar to the previous year as well, with the hairiest cultivars also having the hairiest bracts. Leaf area was not different between the cultivars in 2012. However, the leaf sizes were nearly half of the size of the previous year (Table 7). Moreover, bract size was over 30% higher in 2012 for all cultivars. ST 5458B2RF and DP 0935B2RF had the largest bract size in the study.

In Williamson County in 2011, PHY 499WRF had more than double the leaf trichomes than the next hairy cultivar. DP 1032B2RF and FM 1740B2F exhibited extremely smooth leaves (Table 8). Cotton in Williamson County was not harvested in 2011 due to the extreme drought conditions (Appendix B).

**Table 7.** Leaf and bract characteristics of cultivars from Matagorda County trial in 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| ST 5458B2RF[z] | Hairy | 324.4 a[y] | 31.8 ab | 58.4 a | 9.37 a | 5.42 a |
| PHY 499WRF | Semi-Smooth | 302.4 a | 35.7 a | 63.2 a | 9.02 ab | 5.06 a |
| DP 1044B2RF | Semi-Smooth | 206.4 b | 26.9 c | 57.3 a | 7.84 abc | 4.74 a |
| PHY 367WRF | Semi-Smooth | 125.7 c | 31.1 ab | 59.5 a | 7.06 c | 4.82 a |
| PHY 375WRF | Semi-Smooth | 139.7 c | 30.1 ab | 55.8 a | 7.33 bc | 4.85 a |
| FM 1740B2F | Smooth | 31.2 d | 28.3 b | 61.5 a | 8.47 abc | 5.02 a |
| DP 0935B2RF | Smooth | 21.8 d | 21.2 c | 52.1 a | 9.26 a | 5.29 a |
| P>F | | <0.01 | 0.02 | 0.96 | 0.05 | 0.13 |
| %CV | | 17.9 | 13.5 | 16.8 | 11 | 5.69 |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

**Table 8.** Leaf and bract characteristics of cultivars from Williamson County trials in 2011.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 510.7 a[y] | 51.6 a | 55.6 b | 4.66 a | 4.02 b |
| ST 5458B2RF | Hairy | 248.9 b | 33.7 b | 57.1 b | 4.63 a | 4.04 b |
| PHY 367WRF | Semi-Smooth | 201.0 b | 29.0 b | 80.8 a | 5.03 a | 4.41 a |
| DP 1044B2RF | Semi-Smooth | 167.9 b | 29.0 b | 57.4 b | 4.57 a | 4.04 b |
| FM 1740B2F | Smooth | 9.0 c | 29.5 b | 56.7 b | 4.79 a | 4.5 a |
| DP 1032B2RF | Smooth | 2.6 c | 19.5 c | 67.8 ab | 4.44 a | 4.07 b |
| P>F | | <0.01 | <0.01 | 0.01 | 0.96 | 0.01 |
| %CV | | 24.1 | 14.2 | 11.8 | 17.5 | 3.88 |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

Some differences were observed in leaf area and bract length between cultivars with PHY 367WRF having the largest leaf size and bract length in 2011. No difference in bract size occurred between cultivars.

In 2012, trichomes were densest on PHY 499WRF, about 200 trichome $cm^{-2}$ more than the next hairiest cultivar (Table 9). Bract trichomes exhibited a similar trend as leaf trichomes, a positive correlation of 0.62 (Table 8 and 9; Appendix E.6.). Williamson County data in 2012 for leaf and bract traits were unavailable but trichome data was collected and presented. DP 0935B2RF was the smoothest leaf and bract cultivar in 2012. There was a one score range amongst all cultivars with DP 0935B2RF having the lowest leaf grade scores, and ST 5458B2F having the highest leaf grade score, but there was no significant correlation between leaf grade and trichome density (Fig. 9).

A Tifton, GA location was added in 2012 to determine if similar results and stability of trichome density and plant characteristics were occurring in the Southeastern portion of the Cotton Belt. ST 5458B2F, PHY 367WRF, and DP 1044B2RF had leaf hairiness of between 200 and 300 trichomes $cm^{-2}$ (Table 10) and were half the PHY 499WRF leaf trichome density. FM 1740B2F had categorically fewer leaf trichomes than all the other cultivars. PHY 499WRF had a higher mean bract trichome density and more bract area than all the other cultivars; however, no other cultivars were statistically different ($P \leq 0.05$). Leaf area and bract length were not different at this location. Cotton grown in Tifton exhibited a range of leaf grade values, between 3 and 3.5.

**Table 9.** Analysis summary of leaf and bract characteristics of cultivars from Williamson County, 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 816.8 a[y] | 48.2 a | - | - | - |
| ST 5458B2RF | Hairy | 629.7 b | 30.1 bc | - | - | - |
| DP 1044B2RF | Semi-Smooth | 265.9 c | 30.6 bc | - | - | - |
| PHY 367WRF | Semi-Smooth | 246.7 c | 33.6 bc | - | - | - |
| FM 1740B2F | Smooth | 32.1 d | 35.4 b | - | - | - |
| DP 0935B2RF | Smooth | 9.2 d | 26.1 c | - | - | - |
| P>F | | <0.01 | <0.01 | - | - | - |
| %CV | | 24.6 | 12.1 | - | - | - |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

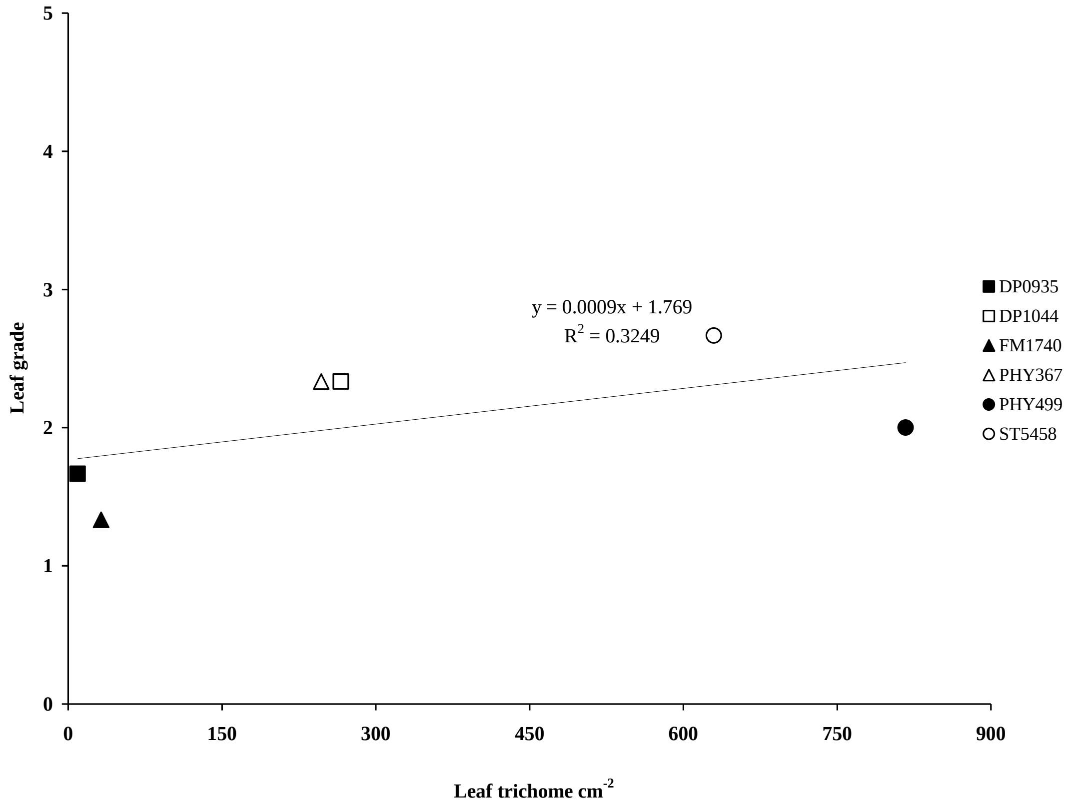



**Figure 9.** Leaf grade as impacted by the density of trichomes on abaxial leaf surfaces of different cultivars[z] grown in Williamson County in 2012. Each value for the respective cultivars was averaged over all replications in this trial. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the trichome density level in this trial (*P* = 0.05). [z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

**Table 10.** Analysis of leaf and bract characteristics of cotton cultivars grown in Tifton, Georgia in 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length |
|---|---|---|---|---|---|---|
| PHY 499WRF[z] | Semi-Smooth | 585.2 a[y] | 52.7 a | 129.6 a | 9.56 a | 4.98 a |
| ST 5458B2RF | Hairy | 290.3 b | 37.5 bc | 117.5 a | 7.98 b | 4.75 a |
| PHY 367WRF | Semi-Smooth | 267.7 b | 39.1 b | 121.4 a | 7.45 bc | 4.71 a |
| DP 1044B2RF | Semi-Smooth | 235.8 b | 33.1 c | 121.5 a | 6.90 c | 4.58 a |
| FM 1740B2F | Smooth | 38.3 c | 39.8 b | 121.4 a | 7.96 b | 4.74 a |
| P>F | | <0.01 | <0.01 | 0.3 | <0.01 | 0.27 |
| %CV | | 15.8 | 9.57 | 6.18 | 9.65 | 4.92 |

[z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

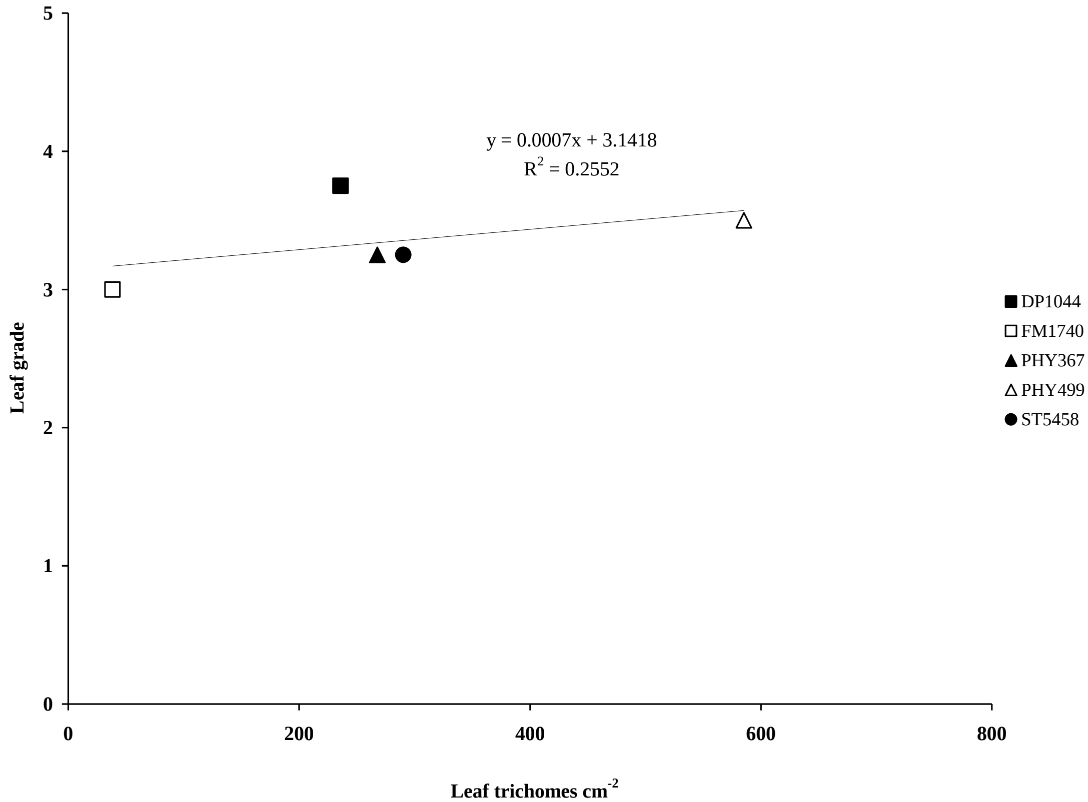



**Figure 10.** Leaf grade as impacted by the density of trichomes on different cultivars[z] grown in Tifton, Georgia in 2012. Each value for the respective cultivars was averaged over all replications in this trial. Kruskal-Wallis test indicated the cotton leaf grade was not influenced by the trichome density level in this trial ($P = 0.05$). [z]Deltapine (DP), Fibermax (FM), Phytogen (PHY), Stoneville (ST)

FM 1740B2R the lowest leaf grade of all the cultivars, and DP 1044B2RF had the highest leaf grade in this study (Fig. 10). Trichome density did not influence the leaf grade based on the Kruskal-Wallis test.

*Module Trials*

Wharton and Williamson counties were selected for a large scale cultivar trial to obtain two different production regions and harvest methods. The same morphological characteristics were monitored on DP 0949B2RF, a light-hairy cultivar, and DP 0935B2RF, a smooth leaf cultivar. Leaf trichome densities for DP 0949B2RF exceeded 330 trichome $cm^{-2}$ at all sites, and was greater than 540 trichome $cm^{-2}$ at the Williamson county location in 2012 (Table 11). At each location, DP 0949B2RF had a higher leaf and bract trichome density than DP 0935B2RF ($P \leq 0.05$). Bract area was larger at each site for the DP 0935B2RF (Table 11). No differences were observed between the leaf and bract length for the two cultivars at any site.

Leaf grade was higher in DP 0949B2RF in both years at the Wharton County location. In 2011, DP 0935B2RF leaf grade value was 50% of DP 0949B2RF (Fig. 11). Both cultivars had leaf grade values of three or higher during the 2012 growing season, but the DP 0935B2RF was a leaf grade value of 0.5 lower than DP 0949B2RF. In both growing seasons, leaf grade values were inversely associated with bract and leaf trichome density (Fig. 11).

Severe drought in 2011 reduced the harvested modules in Williamson County to one module of each cultivar; however, the mean leaf grade value was 0.5 higher for the DP 0949B2RF compared to DP 0935B2RF.

**Table 11.** Module cultivar trial trichome and morphological data in Wharton and Williamson Counties during 2011 to 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| | | | Wharton County 2011 | | | |
| DP 0949B2RF[z] | Light-Hairy | 334.7 a [y] | 30.8 a | 100.2 a | 4.79 b | 4.48 a |
| DP 0935B2RF | Smooth | 7.38 b | 18.2 b | 90.9 a | 5.85 a | 4.61 a |
| Pr>F | | 0.02 | <0.01 | 0.27 | 0.03 | 0.39 |
| %CV | | 28.1 | 8.3 | 10.3 | 7.0 | 4.06 |
| | | | Wharton County 2012 | | | |
| DP 0949B2RF | Light-Hairy | 306.0 a | 41.6 a | 86.8 a | 6.87 b | 4.74 a |
| DP 0935B2RF | Smooth | 12.6 b | 21.0 b | 92.7 a | 9.15 a | 5.19 a |
| Pr>F | | <0.01 | 0.01 | 0.25 | 0.05 | 0.07 |
| %CV | | 15.6 | 9.7 | 6.46 | 13.0 | 4.63 |
| | | | Williamson County 2011 | | | |
| DP 0949B2RF | Light-Hairy | 386.5 a | 37.3 a | 69.8 a | 3.56 b | 4.39 a |
| DP 0935B2RF | Smooth | 4.22 b | 14.0 b | 70.0 a | 5.44 a | 4.50 a |
| Pr>F | | <0.01 | 0.01 | 0.95 | <0.01 | 0.21 |
| %CV | | 21.1 | 23.1 | 6.85 | 6.15 | 2.31 |
| | | | Williamson County 2012 | | | |
| DP 0949B2RF | Light-Hairy | 540.6 a | 49.7 a | - | - | - |
| DP 0935B2RF | Smooth | 4.9 b | 24.7 b | - | - | - |
| Pr>F | | <0.01 | <0.01 | - | - | - |
| %CV | | 31.2 | 15.4 | - | - | - |

[z]Deltapine (DP)
[y] Means followed by the same letter in a column,within a specific environment, are not significantly different (P = 0.05).

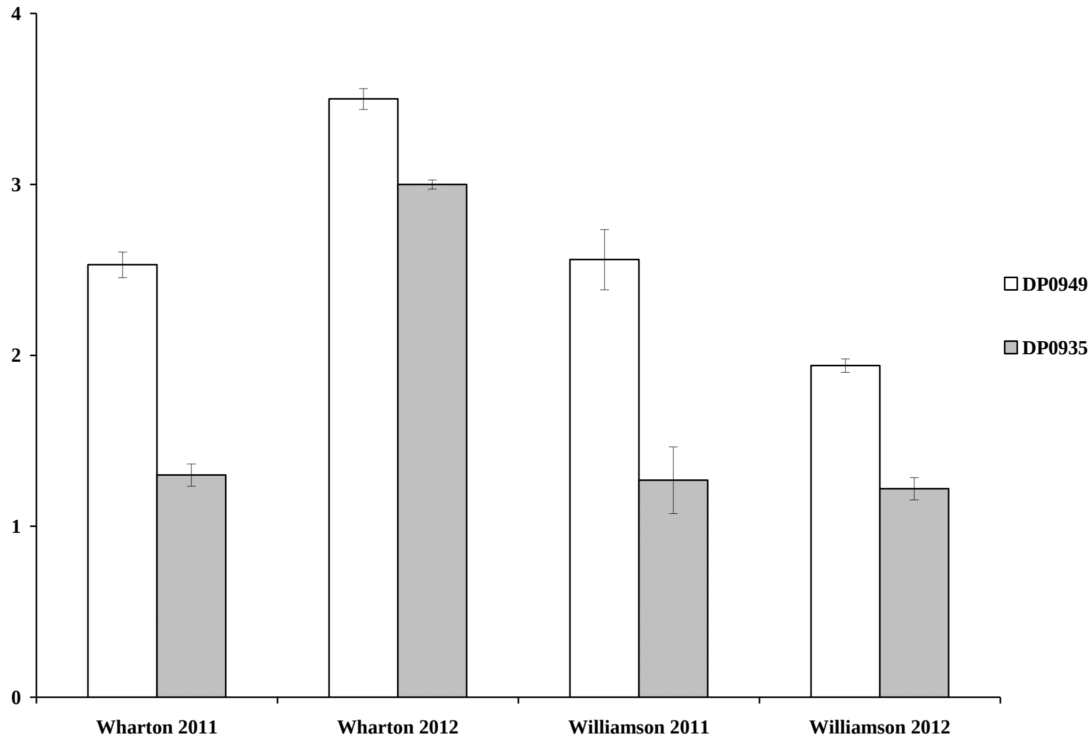



**Figure 11.** Leaf grade of cultivars from module trials conducted in Wharton and Williamson Counties during the 2011 and 2012 growing season. DP 0949B2RF[z] had a higher trichome density at each location than DP 0935B2RF. Kruskal-Wallis test indicated the cotton leaf grade was influenced by trichome density of all locations (*P* = 0.05). Bars represent standard error of each dataset. Deltapine (DP)

Williamson County leaf grade was higher in DP 0949B2RF in both years, and was influenced by trichome density of either leaf or bract (Fig. 11). On average across years, leaf grade values were lower than three, but DP 0935B2RF was nearly one leaf grade value lower than DP 0949B2RF (Fig. 11).

## Conclusions

For multiple cultivar trial locations across the Cotton Belt have shown that the rating of leaf hairiness assigned to a cultivar by the company does not consistently correspond to an objective quantification of leaf trichome density. Inconsistencies in the current rating systems support the previous efforts by Bourland et al. (2003) and Hornbeck and Bourland (2007) to develop a uniform system. Specifically, PHY 499WRF is labeled as a semi-smooth cultivar, but was found to have a higher trichome density than all other cultivars in this trial. The difference in trichome density between semi-smooth and hairy cultivars was not as distinct as with the difference between smooth and semi-smooth. In all locations, some semi-smooth cultivars had higher trichome density than the cultivars labeled as hairy.

Evidence in these trials indicate that amount of leaf and bract materials remaining in ginned lint and resulting in higher leaf grade values can be increased by leaf trichome density. Comparisons of cultivars processed in commercial gins consistently showed that cultivars with higher trichome densities resulted in higher leaf grade values. Data reinforced findings that trichome density influences the efficiency and efficacy of the lint cleaning process through ginning by Rayburn (1988).The differences between hairy and smooth cultivars were typically one leaf grade value, but could be reduced by half.

CHAPTER IV

# COTTON HARVEST AID REGIMES AND THEIR INTERACTION WITH COTTON CULTIVAR CHARACTERISTICS IMPACTING LEAF GRADE

## Overview

Cotton, *Gossypium hirsutum* L., leaf grade values can significantly increase with remnants of leaf and bract materials in cotton lint and can result in discounts to the producer and increased ginning cost. The USDA-AMS Classing office in Corpus Christi, Texas has reported increases in leaf grade values beginning in 2000 (Appendix A) (USDA, 2012). The interaction of morphological characteristics of cotton cultivars and the various harvest aid regimes were evaluated over three growing seasons to identify key factors contributing to the increased leaf grade values. Multiple trials were conducted in Burleson, Colorado, and Matagorda counties in Texas. Cotton cultivars were selected with a range of leaf hairiness and were sprayed with five harvest aid treatments to obtain a range of defoliation and desiccation levels. Leaf and bract pubescence, and leaf and bract area were collected, as well as defoliation and desiccation levels, to analyze the resulting impact on cotton leaf grade values. Visual quantification of leaf and bract trichome density was conducted on the youngest fully-expanded leaves and mid-canopy full sized bolls, respectively, at the physiological cut-out growth stage. A total of 5 to 10 leaf and bract samples were collected from each plot. Cotton was harvested with a spindle picker, seed cotton samples were ginned in a microgin, and lint quality was measured with HVI analysis. Results from trichome quantification indicated substantial variation in cultivars and discrepancies from company based rating systems.

Defoliation level rating ranged from 0 to 84% at 14 days after treatment application. Defoliation or desiccation was not influenced by cultivar and did not impact leaf grade values. Leaf grades values generally increased with higher leaf trichome densities, although not always significantly. Other plant morphological factors did not impact cotton leaf grade values.

## Introduction

The process of preparing cotton *Gossypium hirsutum* L., for harvest, is dynamic, and numerous factors can influence the outcome of defoliation. The successful use of defoliation products and their associated rates is commonly referred to as part “art” and part “science” (Supak and Snipes, 2001). Correctly matching the different variables of defoliation products, product rates, cultivar, and environment can potentially reduce the cotton leaf grade value. During the last decade, cotton leaf grade the leaf and bract material remaining in the lint after ginning, has steadily increased and remains an economic hindrance to producers throughout the Cotton Belt, particularly in the Coastal Bend of Texas (USDA, 2012). From 2000 to 2012, cotton leaf grade scores of 4 substantially increased, except in 2011, where abnormally dry conditions were present during the harvest season. Higher cotton leaf grade values have a detrimental impact on the entire U.S. cotton industry with price reductions to the producer and increased ginning cost for ginners.

Cotton lint quality is determined by fiber characteristics, both physical and visual, which are quantified by High Volume Instrument (HVI) for all the cotton classed in the U.S. Some of the primary physical characteristics of fiber quality include length, strength, elongation, micronaire, and leaf grade; while visual components include brightness, yellowing, and staining (USDA, 2012). Cotton leaf grade is the visual estimate of the quantity of leaf and bract material in the ginned lint sample submitted for HVI analysis. The leaf grade is rated and assigned a value of 1 to 7, with 1 being the lowest leaf contamination score and 7 the highest. Leaf grade values are currently calculated with HVI using a proprietary algorithm comparing particle counts and percent area of trash. Prior to 2011, human classers compared lint samples to universal standards to determine the cotton leaf grade value.

Several agronomic factors are believed to negatively influence the leaf grade values, including: cotton defoliation, late-season weather conditions, and some cotton cultivar characteristics (Anthony and Rayburn, 1989; Morey et al., 1976). The quantity of cotton leaves remaining on the plant at harvest time is a logical contributing factor, including green leaves and leaves desiccated during the pre-harvest application of harvest aid products (Supak and Snipes, 2001). Common late-season weather conditions detrimental to harvest aid efficacy include, late-season rainfall resulting in regrowth and conditions promoting poor application coverage (Seibert and Stewart, 2006). Also, cotton cultivars have morphological differences in leaf size, hairiness, and growth habits, and these factors may also detrimentally impact cotton leaf grade (Novick et al., 1991; Smith, 1964).

Reducing the amount of plant material (leaf, bract, petiole, etc.) in harvested cotton through the ginning process is an important step in improving fiber quality. However, excessive lint cleaning to remove these plant parts can have a negative impact on fiber length and gin turnout (Sui et al., 2010). If the leaf and bract materials cannot be removed during the ginning process, higher leaf grade values will result in discount prices to producers. This price reduction typically begins at a leaf grade value of 4 and results in a significant reduction of 5.95 or more cents per kg (Larson and English, 2001).

### *Defoliation*

Cotton is a perennial plant that is grown as an annual row crop. To improve harvest conditions for mechanical harvesters, harvest aid products can be used to prepare the crop in the fall (Lewis and Richmond, 1968; Fortenberry, 1956). The termination and defoliation of the cotton plant has been proven to be vital to the improvement of harvest conditions and maintaining lint quality and increasing harvest efficiency (Sui et al., 2010; Faircloth et al., 2004; Seibert and Stewart, 2006).

The use of desiccants and defoliants has been intensely studied since the 1930s and continues with various research trials (Cathey, 1986; Faircloth et al., 2004; Snipes and Cathey, 1992; Walhood and Addicott, 1968). The on-going evaluation of harvest aid products is in part to the inconsistencies in the efficacy of harvest aids, development of new products, and the importance of the process for harvest efficiency and to minimize price discount for plant materials (Valco and Snipes, 2001).

Several factors are known to impact the success of defoliation which include: harvest aid product(s), plant condition; weather prior to, during, and following application; spray coverage; canopy density; translocation of chemicals; and varietal traits (Cathey, 1986; Oosterhuis et al., 1991). Studies have investigated varying components of cotton defoliation and have reported difficulties in making broad recommendations (Oosterhuis et al., 1991; Seibert and Stewart, 2006; Valco and Snipes, 2001). Furthermore, application timing and harvest aid treatments had relatively inconsistent effects on trash and leaf grade when compared on ultra-narrow row cotton (Larson et al., 2005). Additional inconsistencies were found by Seibert and Stewart (2006) when comparing different cotton fields, which resulted in the conclusion that harvest aid selection should be based on individual fields and environments.

Similar to other dicot plants, the natural physiological process of leaf senescence involves the increased production of ethylene and other precursors that down regulate auxin production within the leaf which promotes the abscission layer formation (Guinn, 1986; Morgan, 1984; Morgan and Durham, 1975). Application of defoliation products promotes the development of ethylene production and leaf senescence from the cotton plant (Addicott, 1982; Sexton et al., 1985; Cathey, 1986). Harvest aid products have several different modes-of-action, which can impact the overall efficacy (Siebert, et al. 2006). Hormonal harvest aids produce senescence by directly promoting ethylene evolution within the plant (Suttle, 1988). Defoliants, such as, ethephon, thidiazuron, cyclanilide, dimethipin, and others, interact with plant cells to promote ethylene production in different ways. Herbicide based harvest aid products injure the plant and promote an ethylene response, which results in leaf abscission. Desiccating harvest aid products include paraquat and sodium chlorate, both which are strong contact based herbicides that have limited translocation (Scandalios, 1993). With both herbicidal and desiccant harvest aid products, when the abscission layer does not fully form prior to the desiccation of the leaf; the desiccated leaves remain tightly attached to the plant. This can result in a dry, dead leaf attached to the plant at the time of harvest and will be pulled into the harvester along with the seed cotton. When evaluating harvest aid products, these desiccated leaves are rated as the percentage of total leaves on the plant. Drying of the leaves can be very important in reducing moisture during the storage of modules, specifically for stripper harvested cotton.

Different harvest aid products can be combined to synergize the effects of the active ingredients, and this can occur at the product level or as a tank mix. For example, thidiazuron and diuron are combined into a single product, where thidazuron inhibits auxin transportation, while diuron promotes ethylene production by inhibiting photosynthesis and promoting stress within the cell (Suttle, 1988, Zer and Ohad, 1995). Regardless of the product or mode-of-action, leaf removal by any of these harvest aid products will result in a plant with a reduced amount of leaf canopy at harvest time and increase harvest efficiency.

### *Cultivar Hairiness*

Leaf grade values of the ginned lint can be impacted by the plant pubescence, or hairiness, of the cotton cultivar, which is determined by the presence and density trichomes (Anthony and Rayburn, 1989; Rayburn, 1988). Trichomes are hair-like protrusions on the surface of the plant parts (Bradow and Wartelle, 1998; Oosterhuis and Jernstedt, 1999). Cotton trichomes on leaves, leaf margins and stems are genetically controlled by multiple alleles at five loci (Percy and Kohel, 1999). Some of these alleles can affect different plant tissues and organs. Trichome densities between different regions of the leaf have strong positive correlations to each other (Smith, 1964).

Both Rayburn (1988) and Anthony and Rayburn (1989) compared smooth and hairy cultivars together to determine the effect on trash remaining in the lint following ginning. Lint from smooth leaf cultivars was easier to clean during the ginning process and thus had lower leaf grade values (Rayburn and Libious, 1983; Anthony and Rayburn, 1989). Leaf trichome density also has other implications on cotton management. An increase in the density of trichomes of a cotton cultivar has been reported to influence the preferential feeding of some insect pests. Mekala (2013) reported cotton fleahoppers density increased with increasing trichome density. Jenkins and Wilson (1996) and Norman and Sparks (1997) reported increased susceptibility to whiteflies for cotton cultivars with more dense trichomes and an increased insecticide applications to control whiteflies.

Bracts are modified leaves that surround the developing flower bud and boll on the cotton plant. Cotton bracts are a major contributor to leaf trash in harvested lint (Morey et al., 1976). Alteration of the bract morphology has been attempted by breeders in the past. However, bract size reduction, or reducing their persistence, has shown to negatively impact the overall plant physiology, and relative bract size is influenced by environmental conditions, such as drought (Bourland and Hornbeck, 2007; Wullschelger et al., 1990; Zhao and Oosterhuis, 2000).

Current universal industry standards for leaf trichome density ratings do not exist, and all ratings are subject to a company's proprietary process and scale as leaf hairiness.  Norman and Sparks (1997) found that while some cultivars maintained stable trichome densities over multiple years, many have wide variations across years. Standard trichome ratings have been proposed by various sources, but none have been fully adopted by the cotton industry (Bourland and Hornbeck, 2007; Smith, 1964; Rayburn, 1986).  Smith (1964) evaluated cotton trichomes grown in Alabama and found a range of 2 to 205 trichomes $cm^{-2}$, where a Deltapine Smooth Leaf cultivar was viewed as the standard for the smooth leaf cultivar in his ratings.  To study cotton hairiness, Rayburn (1986) separated cultivars into smooth and hairy categories, prior to the development and commercial release of reduced hairy cultivars that were an intermediate in hairiness.  Rayburn (1986) quantified leaf trichomes, and proposed a three class system of “smooth”, “moderately hairy”, and “hairy”.  Bourland et al. (2003) noted that following this study the release and classification of multiple cultivars as “reduced hair” became available to Delta producers as “semi-smooth” cultivars.  The most objective rating method published is the quantification of the trichomes proposed by Bourland et al. (2003), where trichome density is quantified at the base of the leaf on the abaxial side.  However, quantification of leaf trichome densities has not been adopted by the industry, in part, due to the time required to quantify the trichome density.  Bourland et al. (2003) developed a visual rating system for leaf hairiness (1-9) based on abaxial leaf trichome density.  Bourland and Hornbeck (2007) proposed another method that increased the efficiency of leaf hairiness ratings, but their methodology was subjective and has not been widely adopted.

Variation between seasons and within a single plant depending on the location within the canopy has been found in leaf trichome density (Bourland et al., 2003). Minimizing variation by utilizing uniform collection methods is vital to proper rank analysis of cultivars. Bourland et al. (2003) collected leaf samples from three canopy regions and compared trichome densities. The trichome density decreased on more mature leaves and was attributed to the physical wearing off of the trichomes. Therefore, Bourland et al. (2003) identified the leaves five nodes from the apex, the first fully expanded leaf, as the best representation of the plant's trichome density. Dimitropoulou et al. (1980) found differences in trichome densities between cultivars when studying the distribution of bract trichomes on the abaxial and adaxial surfaces rather than marginal trichomes. Additional testing on marginal bract trichome density found that mid-canopy, first position bolls were the best representation of bract trichomes (Bourland and Hornbeck, 2007; Hornbeck and Bourland, 2007). The relationship between bract trichome density and leaf trichome density were positively correlated, with values of 0.35 and 0.33 in 2001 and 2002, respectively, within a segregating $F_2$ population (Hornbeck and Bourland, 2007).

## *Objectives*

The objective of this study was to identify the key interactions between the level of defoliation and desiccation and cultivar characteristics, and their impact on cotton leaf grade values.

## Materials and Methods

### *Cultural Practices*

In the Upper Coastal Bend of Texas, Colorado and Matagorda Counties, five harvest aid treatments were superimposed over a hairy leaf cultivar Stoneville 5458B2RF (ST 5458B2RF) and smooth leaf cultivar, Dynagro 2570B2RF (DG 2570B2RF). At the Texas A&M AgriLife Research Farm in Burleson County in 2011 and 2012, four cultivars, Deltapine 0949B2RF (DP 0949B2RF), Deltapine 0935B2RF (DP 0935B2RF), Fibermax 1740B2F (FM 1740B2F), and ST 5458B2RF received the same five harvest aid treatments. Soil types were a Weswood silt loam (fine-silty, mixed, superactive, thermic, Udifluventic Haplustepts) in Burleson County for all years of the study, Norwood silty clay loam (fine-silty, mixed, superactive, hyperthermic fluventic eutrudepts) in Colorado County during the 2010 and 2012 growing seasons, and Laewest clay (fine, smectitic, hyperthermic typic hapluderts) in Matagorda County during the 2011 growing season. Cotton was planted mid-April and managed under local practices recommended by the Texas A&M AgriLife Extension Service. Supplemental irrigation was used as needed in the Burleson County location all seasons to ensure average yields. In Colorado County the trial was irrigated and non-irrigated in 2010 and 2012, respectively. The Matagorda County location was a non-irrigated site. Below normal precipitation occurred at all locations in 2011. Plot dimensions were four rows with row spacing of 1.02 meters wide by 12.2 meters long. An alleyway was created between each replication during mid-season.

## *Treatment Application and Experimental Design*

Treatments were arranged in a split-plot design with four replications. Five defoliation treatments were selected and applied to obtain a wide range of defoliation and desiccation levels in all years and locations (Table 12). Each trial contained an untreated check treatment, where only water was applied. Treatments for all studies were applied in a single pass with a four row Lee Spider sprayer with a spray volume of 103 L $ha^{-1}$ using XR flat fan tip. The initial harvest aid application was applied 14 days prior to expected harvest, when the crop was approximately 65% open bolls. All sequential applications were applied seven days after the initial application and one week before expected harvest.

Each experimental unit was harvested mechanically with a small plot spindle picker. One of the center two rows of each plot was harvested in the Coastal Bend counties with an International Farmall H cotton picker. The two middle rows of each plot were harvested in the Burleson County trials with a two-row John Deere 9910 cotton picker.

## *Data Collection*

### Leaf Sampling

Morphological plant data were collected in 2011 and 2012 from leaves and bracts, including leaf trichomes, bract trichomes, leaf size, bract size, and bract length. At cutout (5 nodes above white flower) leaf and bract samples were collected from each cultivar. In 2011, five leaves and five bolls were sampled, and sample size was increased to ten leaves and ten bolls in 2012. Leaves were selected from fully expanded leaves located five nodes from the apex of the plant as recommended by Bourland et al. (2003). Bract sampling was conducted on bracts from a full-size, first position boll near the center of the plant (Bourland and Hornbeck, 2007). One bract was removed from the base of each of the sampled bolls. Leaf and bract samples were placed in a cooler, at approximately 10 degrees C in the field and were transferred to a refrigerator at 4 degrees C until trichomes were quantified within 7 days after field collection. Leaf and bract area was calculated using a Li-Cor 3100 leaf area meter (LI-COR Inc., Lincoln, NE).

Leaf trichome densities were determined by counting trichomes on abaxial, mid-vein areas of each leaf using an index card with a 0.65 cm diameter hole ($0.33cm^2$), and were subsequentially converted to trichomes per square centimeter (Hornbeck and Bourland, 2007). Margin trichome density was determined for bracts by counting two margin areas of the center tooth of the bract and averaging the values (Bourland et al., 2003; Bourland and Hornbeck, 2007; Hornbeck and Bourland, 2007). Trichomes were counted with the aid of a dissecting microscope.

**Late Season Measurements**

Prior to harvest aid treatment application, open boll percentage was estimated, and harvest aids were applied at about 65% open bolls. Percent defoliation, desiccation, and green leaf were visually rated at 7 and 14 days after treatment (DAT) from the center two rows of each treatment. These measurements were taken by the same person throughout the entirety of the study. Regrowth was rated for all plots 14 DAT, immediately prior to harvest (Appendix C). Untreated check treatments were rated as zero and complete absence of leaves was 100%. The untreated check for each replicate was rated first to provide a baseline to rate the harvest aid treatments.

**Lint Measurements**

Harvested cotton was collected in large mesh sacks and was stored in a dry location for 1 to 3 weeks prior to processing. A subsample of seed cotton weight approximately 500 g was pulled for each plot and was ginned in a microgin. The gin machinery sequence included: seed cotton intake, two-saw stick machines, an extraction feeder, a ten-saw gin stand, and a single lint cleaner. This was designed to be representative of the ginning facilities currently in use. Ginned lint samples were delivered to the Texas Tech University Fiber and Biopolymer Institute and the fiber quality parameters were processed using HVI analysis. Lint quality characteristics quantified by HVI included length, strength, micronaire, brightness, yellowness, color grade and leaf grade.

*Data Analysis*

The interaction between harvest aids and cultivar traits were analyzed as a split plot trial using Statistical Analysis System (SAS) for personal computers, version 9.2 (SAS Institute, 2007). A Bartlett's test was conducted to confirm homogeneity of variance prior to conducting an analysis of variance test. The General Linear Model was used for the analysis of variance ($P \leq 0.05$). Data from multiple locations and years were found to have a treatment by environment interaction for defoliation, desiccation, and morphological measurements preventing the combining of data across locations or years . Additionally, there was no interaction found between the harvest aid treatments and cultivars for any individual trial. As a result, data were pooled across cultivars and a Protected Fischer's least significant difference test at $P = 0.05$ was used to separate means. Leaf grade values were treated as non-parametric data and were non-normal in distribution. The Kruskal-Wallis test at $\alpha = 0.05$, capable of processing non-parametric and non-normal data, was used to determine if variables, such as, defoliation, desiccation, leaf trichome density, and bract trichome density affected the leaf grade value within individual environments. Pearson's correlations and Spearman correlations, for nonparametric data, were used to analyze data on all trials (Appendix E).

## Results and Discussion

*Two Cultivars by Five Harvest Aids*

**Defoliation**

Defoliation of Dynagro 2570B2RF (DG 2570B2RF) and Stoneville 5458B2RF (ST 5458B2RF) was analyzed in the Upper Coastal Bend, and there was no cultivar interaction with harvest aid treatments ($P=0.61$) during any year of the study. Locations and years were analyzed individually due to significant interactions in defoliation, desiccation, and leaf grade ($P \leq 0.01$).

In 2010, a wide defoliation range, over 70%, was obtained with the various harvest aid treatments. The maximum defoliation level achieved by the sequential application of thidiazuron at 112 g AI $ha^{-1}$ followed by carfentrazone-ethyl at 17.5 g AI $ha^{-1}$ (Table 12). Differences in desiccation levels were observed among the treatments and the untreated check; however, the highest desiccation level was only 3% for the carfentrazone-ethyl at 17.5 g AT $ha^{-1}$ (Table 12). In 2011, the sequential thidiazuron at 112 g AI $ha^{-1}$ followed by carfentrazone-ethyl at 17.5 g AI $ha^{-1}$ again provided the greatest level of defoliation, as well as, the highest level of desiccation (Table 12). A much more narrow range of defoliation and desiccation levels were observed from the harvest aid treatments. In 2012, all harvest aid treatments effectively defoliated the cotton between 70 and 80%, and no differences in defoliation or desiccation were observed between harvest aid products (Table 12).

**Cultivar Traits**

Trichome densities, leaf size and bract traits were found to have treatment by location interaction and were analyzed individually. ST 5458B2RF trichome densities were much higher, 278 trichomes $cm^{-2,}$ than DG 2570B2RF (Table 13). Additionally, trichome densities were lower for bracts than leaves, but differences were observed. No varietal differences were observed between the other morphological characteristics, including leaf area, bract area, and bract length. In 2012, the difference between the cultivars was less, 213 trichome $cm^{-2}$, but differences were highly significant ($P<0.01$). Bract trichome density was highest for ST 5458B2RF (Table 13). Bracts were longer for DG 2570B2RF, but no other differences were observed in leaf or bract area between the cultivars. Norman and Sparks (1997) reported differences of 10-fold variation within a cultivar over years in the Rio Grande Valley of Texas, but our findings more closely matched Bourland et al. (2003) findings of consistent trichome densities within certain cultivars over years.

**Table 12.** Plant condition 14 days after application of harvest aid treatments in Upper Coastal Bend averaged across cultivars.

| ID | Treatment[z] | g AI $ha^{-1}$ | Timing[y] | Defoliation (%) | Desiccation (%) |
|---|---|---|---|---|---|
| | | | | Colorado County 2010 | |
| 1 | Thidiazuron | 112 | A | | |
| | Tribufos | 210 | A | 52.0 c[x] | 1.38 b |
| | Ethephon | 1102 | A | | |
| 2 | Thidiazuron | 112 | A | 66.5 b | 1.25 b |
| 3 | Thidiazuron | 112 | A | 82.9 a | 1.0 b |
| | Carfentrazone-ethyl[w] | 17.5 | B | | |
| 4 | Carfentrazone-ethyl[w] | 17.5 | A | 13.0 d | 3.25 a |
| 5 | Untreated ($H_2O$) | 0 | A | 0 e | 0 c |
| | | | Pr>F | <0.01 | <0.01 |
| | | | %CV | 36.2 | 49.2 |
| | | | LSD | 10.9 | 0.48 |
| | | | | Matagorda County 2011 | |
| 1 | Thidiazuron | 112 | A | | |
| | Tribufos | 210 | A | 65.2 b | 0.63 abc |
| | Ethephon | 1102 | A | | |
| 2 | Thidiazuron | 112 | A | 69.9 ab | 0.5 bc |
| 3 | Thidiazuron | 112 | A | 83.8 a | 1.62 a |
| | Carfentrazone-ethyl[w] | 17.5 | B | | |
| 4 | Carfentrazone-ethyl[w] | 17.5 | A | 74.0 ab | 1.38 ab |
| 5 | Untreated ($H_2O$) | 0 | A | 0 c | 0 c |
| | | | Pr>F | <0.01 | 0.02 |
| | | | %CV | 26.9 | 125.9 |
| | | | | Colorado County 2012 | |
| 1 | Thidiazuron | 112 | A | 78.4 a | 0.67 a |
| | Tribufos | 210 | A | | |
| | Ethephon | 1102 | A | | |
| 2 | Thidiazuron | 112 | A | 78.6 a | 0.5 a |
| 3 | Thidiazuron | 112 | A | 77.9 a | 0.25 a |
| | Carfentrazone-ethyl[w] | 17.5 | B | | |
| 4 | Carfentrazone-ethyl[w] | 17.5 | A | 69.8 a | 0.25 a |
| 5 | Untreated ($H_2O$) | 0 | A | 0 b | 0 a |
| | | | Pr>F | <0.01 | 0.48 |
| | | | %CV | 18.7 | 211.1 |

[z]Treatments applied at 102.9 L $Ha^{-1}$

[y]Timing B treatments were applied 7 days after initial application of treatment A.

[x]Means followed by the same letter in a column, within a specific environment, and across all cultivars, are not significantly different at $P \leq 0.05$

[w]Treatments contained a non-ionic surfactant at 0.25% volume rate.

**Table 13.** Leaf and bract characteristics of cultivars grown in Upper Coastal Bend during 2011 and 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| | | Matagorda County 2011 | | | | |
| ST 5458B2RF[z] | Hairy | 285.2 a[y] | 36.0 a | 119.0 a | 5.44 a | 3.72 a |
| DG 2570B2RF | Semi-Smooth | 7.38 b | 25.2 b | 115.7 a | 4.84 a | 3.78 a |
| Pr>F | | <0.01 | <0.01 | 0.55 | 0.18 | 0.8 |
| %CV | | 17.4 | 6.36 | 5.82 | 9.33 | 8.17 |
| | | Colorado County 2012 | | | | |
| ST 5458B2RF | Hairy | 241.8 a | 41.9 a | 68.5 a | 9.52 a | 4.98 a |
| DG 2570B2RF | Semi-Smooth | 28.0 b | 27.9 b | 67.8 a | 7.98 a | 4.46 b |
| Pr>F | | <0.01 | <0.01 | 0.85 | 0.19 | 0.04 |
| %CV | | 18.1 | 8.83 | 7.5 | 14.6 | 4.56 |

[z]Dynagro (DG), Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

**Leaf grade**

Defoliation and desiccation were found to have no impact on cotton leaf grade for either the semi-smooth or hairy cultivar. Valco and Snipes (2001) found that an untreated check had the lowest percent area trash of seven defoliation techniques throughout the entire Cotton Belt. These findings support the finding in this study that harvest aid selection is not a deciding factor for increasing leaf grade values. Trichome densities were not quantified for either cultivar in 2010; however, ST 5458B2RF had the highest leaf grade score, a one score increase over DG 2570B2RF (Fig. 12).

During 2011 and 2012, there was a varietal impact on leaf grade values with higher leaf grade values corresponding to increased leaf trichome density. Overall leaf grades were lowest in 2011 (Fig. 12) with 85% of all treatments measuring a leaf grade value of one (Fig. 13). Plots with a leaf grade value of 2 in 2011 had double the trichome density of plots with a leaf grade value of 1. In 2012, leaf grades returned to levels comparable to 2010 and ST 5458B2RF leaf grade value was one score higher than DG 2570B2RF (Fig. 12). More than 50% of all plots harvested in 2012 were rated with a leaf grade of 3 or greater (Fig. 13). Leaf grade was found to be influenced by the density of trichomes in 2012. The average trichome density of plots with a leaf grade score of 1 was 50 trichomes $cm^{-2}$ (Fig. 13). The trichome density tripled for plots with leaf grade values of 3, and reached 250 trichomes $cm^{-2}$ for leaf grade scores of 4 in 2012 (Fig. 13). These findings reaffirm the findings by Rayburn (1988), who concluded smooth leaf cultivars will have less trash than hairy leaf cultivars.

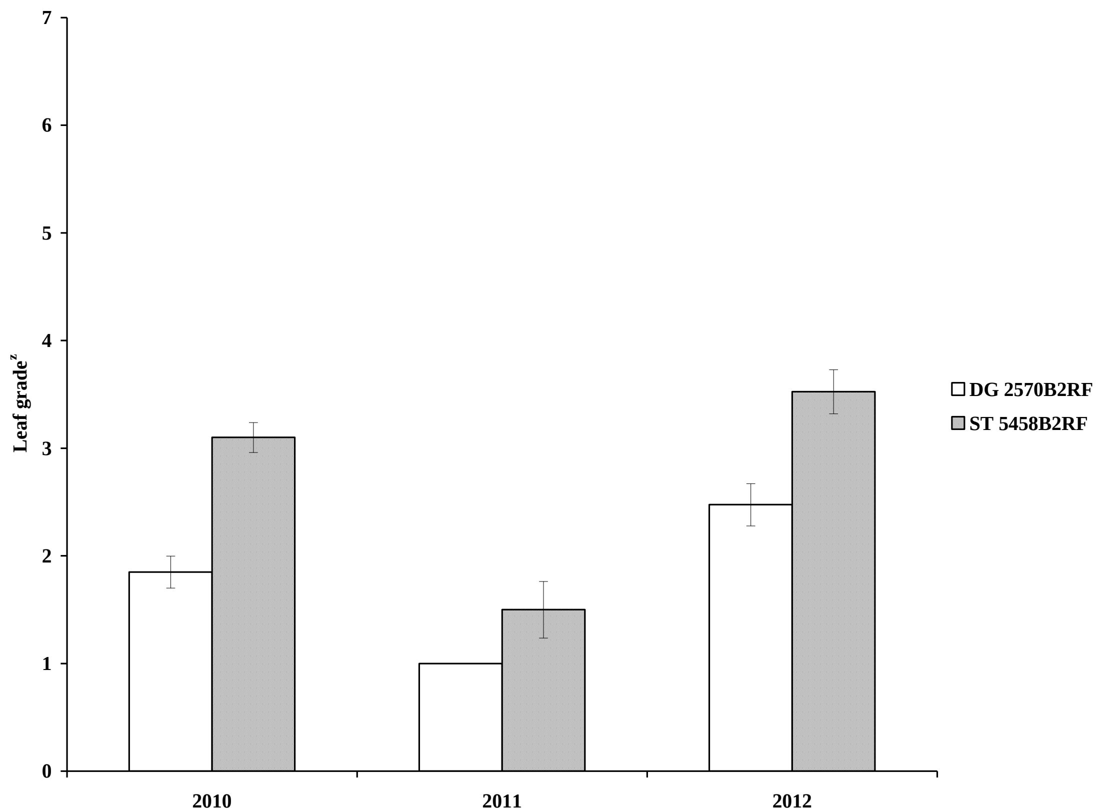



**Figure 12.** Leaf grade of cultivars from cultivar by harvest aid trials conducted in Colorado and Matagorda Counties during the 2010 to 2012 growing seasons. ST 5458B2RF[z] had a higher trichome density at each location than DG 2570B2RF. Kruskal-Wallis test indicated the cotton leaf grade was influenced by trichome density for all seasons ($P = 0.05$). Error bars represent standard error for the given data.
[z]Dynagro (DG), Stoneville (ST)

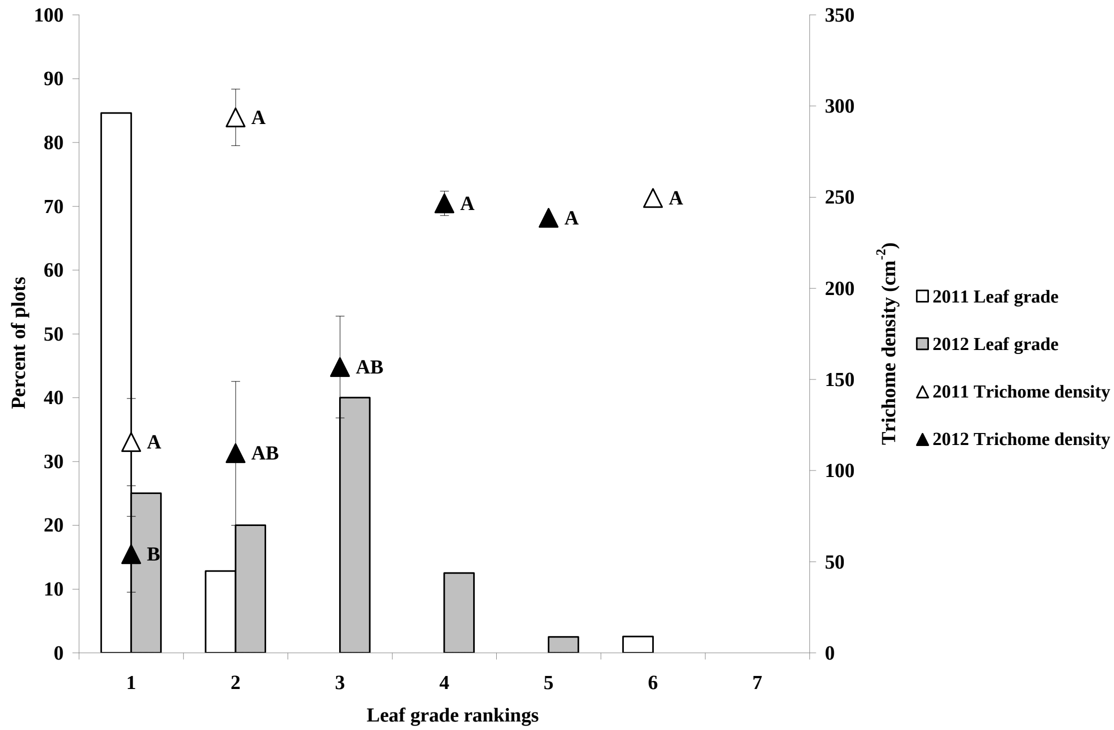



**Figure 13.** Analysis of leaf grade occurrences and leaf trichome density averages for leaf grade categories from cultivar by harvest aid trials conducted in Colorado and Matagorda Counties during the 2011 and 2012 growing seasons. Kruskal-Wallis test indicated the cotton leaf grade was influenced by trichome density both seasons ($P$ = 0.05). Trichome densities averages were significantly different between leaf grade values in both seasons. Means followed by the same letter in the same series are not significantly different (P = 0.05). Error bars represent the standard error of each point.

Additionally, Anthony and Rayburn (1989) found that smooth leaf cultivars had high amounts of foreign materials removed during the cleaning process, resulting in a more ideal leaf rating.

*Four Cultivars by Five Harvest Aids*

In the Burleson County trials defoliation efficacy was not impacted by cultivar (P=0.6) during any year of the study. Therefore, harvest aid treatments were combined and agree with findings by Valco and Snipes (2001). Each location was analyzed individually and was presented individually due to significant interactions of environment by defoliation, desiccation, and leaf grade ($P \leq 0.01$).

In 2011, a wide range of defoliation levels were obtained with the selected harvest aid treatments; however, no harvest aid treatment exceeded 73%. A tank mix of thidiazuron at 112 g AI $ha^{-1}$, 210 g AI $ha^{-1}$ of tribufos, and 1102 g AI $ha^{-1}$ of ethephon, as well as, a sequential of thidiazuron at 112 g AI $ha^{-1}$ followed by carfentrazone-ethyl at 17.5 g AI $ha^{-1}$ provided the best defoliation and were better than the other treatments in 2011 (Table 14). The tank mix of thidiazuron at 112 g AI $ha^{-1}$, 210 g AI $ha^{-1}$ of tribufos, and 1102 g AI $ha^{-1}$ of ethephon also provided the highest level of desiccation, 4.6%, and was higher than the other treatments. In 2012, three of the treatments had defoliation levels between 70% and 72% and were all higher than the carfentrazone-ethyl at 17.5 g AI $ha^{-1}$ treatment (Table 14). Desiccation was not different between the harvest aid treatments in 2012.

**Table 14.** Plant condition 14 days after application of harvest aid treatments in Burleson County averaged across four cultivars.

| ID | Treatment[z] | g AI $ha^{-1}$ | Timing[y] | Defoliation (%) | Desiccation (%) |
|---|---|---|---|---|---|
| | | | | Burleson County 2011 | |
| 1 | Thidiazuron | 112 | A | | |
| | Tribufos | 210 | A | 72.9 a[x] | 4.6 a |
| | Ethephon | 1102 | A | | |
| 2 | Thidiazuron | 112 | A | 49.8 b | 0.6 c |
| 3 | Thidiazuron | 112 | A | 71.2 a | 2.7 b |
| | Carfentrazone-ethyl[w] | 17.5 | B | | |
| 4 | Carfentrazone-ethyl[w] | 17.5 | A | 40.1 c | 1.6 bc |
| 5 | Untreated ($H_2O$) | 0 | A | 0 d | 0 c |
| | | | Pr>F | <0.01 | <0.01 |
| | | | %CV | 26.9 | 138.2 |
| | | | | Burleson County 2012 | |
| 1 | Thidiazuron | 112 | A | | |
| | Tribufos | 210 | A | 71.9 a | 0.6 ab |
| | Ethephon | 1102 | A | | |
| 2 | Thidiazuron | 112 | A | 72.0 a | 0.1 b |
| 3 | Thidiazuron | 112 | A | 70.8 a | 0.8 a |
| | Carfentrazone-ethyl[w] | 17.5 | B | | |
| 4 | Carfentrazone-ethyl[w] | 17.5 | A | 34.6 b | 0.1 b |
| 5 | Untreated ($H_2O$) | 0 | A | 0 c | 0 b |
| | | | Pr>F | <0.01 | 0.06 |
| | | | %CV | 33.2 | 281.4 |

[z]Treatments applied at 102.9 L $ha^{-1}$.

[y]Timing B treatments were applied 7 days after initial application of treatment A.

[x]Means followed by the same letter in a column, within a specific environment, and across all cultivars, are not significantly different at $P \leq 0.05$.

[x]Treatments contained a non-ionic surfactant at 0.25% volume rate.

Two hairy and two smooth leaf cultivars were selected based on company ratings for the Burleson County location, and quantification of the trichome densities confirmed differences among the smooth and hairy cultivars ($P<0.01$). DP 0949B2RF had the highest trichome density, and DP 0935B2RF had the lowest trichome density in 2011, a range of 330 trichomes $cm^{-2}$ (Table 15). Bract trichome densities followed a similar trend as the leaf trichome density with DP 0949 B2RF and DP 0935 B2RF; however, ST 5458B2F and FM 1740B2F were similar in bract trichome densities. Bract area and bract length values were higher for DP 0935B2RF. Also, DP 0949 B2RF had a lower bract area than other cultivars. No differences were observed in leaf area among the cultivars.

Mean leaf trichome density was lower in 2012 compared to 2011. The leaf trichome densities were separated into four statistical groupings compared to two groupings in 2011. However, the leaf trichome density rankings remained the same in both years (Table 15). Bract trichome densities were ranked identical to the leaf trichome rankings; however, ST 5458B2F and FM 1740 B2F had statistically similar densities. No differences were observed in leaf area among any of the cultivars. Bract area was inversely related to leaf trichome density, in 2012.

Leaf grade values were positively influenced by leaf trichome density in both seasons. ST 5458B2RF had the highest leaf grade in 2011 (Fig. 14). Hairy cultivars, ST 5458B2RF and DP 0949B2RF, had an average increase of one leaf grade score, compared to two smooth cultivars (Fig. 14). Similarly, smooth leaf cotton cultivars have been linked to improved seed cotton cleaning efficiency by Novick et al. (1991).

**Table 15.** Leaf and bract characteristics of cultivars grown in Burleson County for analysis of harvest aid and cultivar effects on cotton leaf grade in 2011 and 2012.

| Cultivar | Company Rating | Leaf Trichomes ($cm^{-2}$) | Bract Trichomes ($cm^{-1}$) | Leaf Area ($cm^2$) | Bract Area ($cm^2$) | Bract Length (cm) |
|---|---|---|---|---|---|---|
| | | Burleson County 2011 | | | | |
| DP 0949B2RF | Light-Hairy | 331.0 a | 38.4 a | 108.0 a | 4.09 c | 4.85 b |
| ST 5458B2RF | Hairy | 274.4 a | 29.7 b | 101.4 a | 5.74 a | 4.93 b |
| FM 1740B2F | Smooth | 10.4 b | 26.9 b | 99.0 a | 5.29 b | 4.89 b |
| DP 0935B2RF | Smooth | 1.36 b | 19.3 c | 106.5 a | 5.99 a | 5.25 a |
| Pr>F | | <0.01 | <0.01 | 0.9 | 0.01 | 0.19 |
| %CV | | 26.6 | 13.4 | 18.5 | 12.9 | 5.26 |
| | | Burleson County 2012 | | | | |
| DP 0949B2RF | Light-Hairy | 257.6 a | 40.7 a | 121.4 a | 7.77 d | 4.84 b |
| ST 5458B2RF | Hairy | 214.7 b | 30.1 bc | 104.2 a | 10.2 c | 5.00 b |
| FM 1740B2F | Smooth | 42.9 c | 34.1 ab | 103.9 a | 10.9 b | 5.11 b |
| DP 0935B2RF | Smooth | 6.48 d | 25.0 c | 97.5 a | 11.8 a | 5.56 a |
| Pr>F | | <0.01 | 0.02 | 0.15 | <0.01 | 0.01 |
| %CV | | 17.4 | 15 | 12.7 | 9.8 | 4.69 |

[z]Deltapine(DP), Fibermax (FM), and Stoneville (ST)

[y]Means followed by the same letter in a column are not significantly different (P = 0.05).

Less than 10% of cotton samples in 2011 were rated higher than a leaf grade of 3, and 50% of the samples had a leaf grade value of 1 (Fig. 15). Low leaf grade values for this trial were likely the result of low precipitation prior to harvest and favorable harvest conditions (Appendix A and B). Trichome density averages for samples with greater than 1 leaf grade values were 250 trichomes $cm^{-2}$ (Fig. 15). In 2012, leaf grade values were not influenced by the cultivar but were impacted by the overall trichome density (Fig. 14 and 15). No leaf grade scores of 1 were reported in 2012 and 70% of scores were greater than 4. Trichome densities doubled from leaf grades of 2 to 3.
Leaf grade scores of 6 consisted of 5% of all samples in 2012, and had a leaf trichome density of greater than 200 trichomes $cm^{-2}$ (Fig. 15).

## Conclusions

Cotton cultivars with varying levels of leaf trichome density did not impact the defoliation or desiccation efficacy of the harvest aid products. These environmental impacts on harvest aid efficacy have also been reported in previous harvest aid research (Logan and Gwathmey, 2002; Oosterhuis et al., 1991). The rankings of cultivars based on leaf trichome density were comparable across locations and years. More dense leaf trichomes were highly correlated with bract trichome densities.

In addition to cotton morphological differences between sites and years, cotton leaf grade values were variable between growing seasons, with the lowest scores occurring in 2011. Differences between years were very distinct; 2011 was one of the worst droughts in Texas, and resulted in low leaf grade scores (Fig. 12).

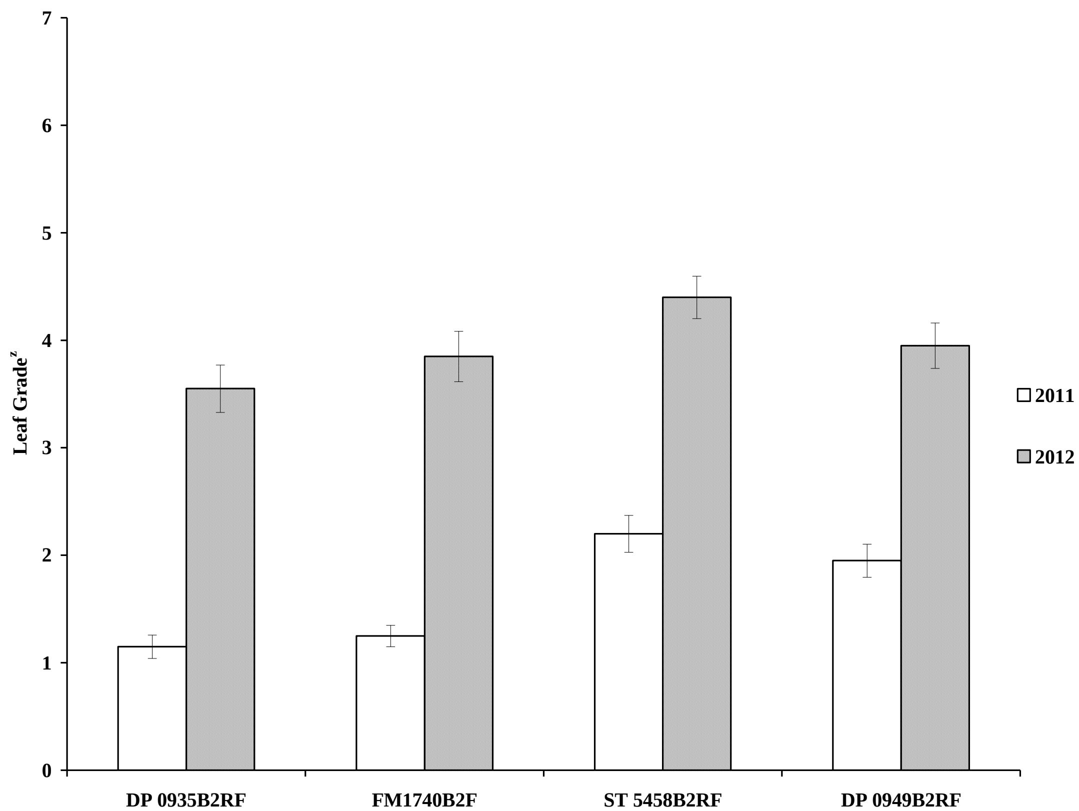



**Figure 14.** Leaf grade of cultivars from cultivar by harvest aid trials conducted in Burleson County during the 2011 and 2012 growing seasons. ST 5458B2RF[z] and DP 0949B2RF had a higher trichome density in both years than DP 0935B2RF and FM 1740B2F. Kruskal-Wallis test indicated the cotton leaf grade was influenced by trichome density both seasons ($P$ = 0.05). Error bars represent standard error of the data. There was a significant year interaction preventing the comparison across years.
[z]Deltapine(DP), Fibermax (FM), and Stoneville (ST)

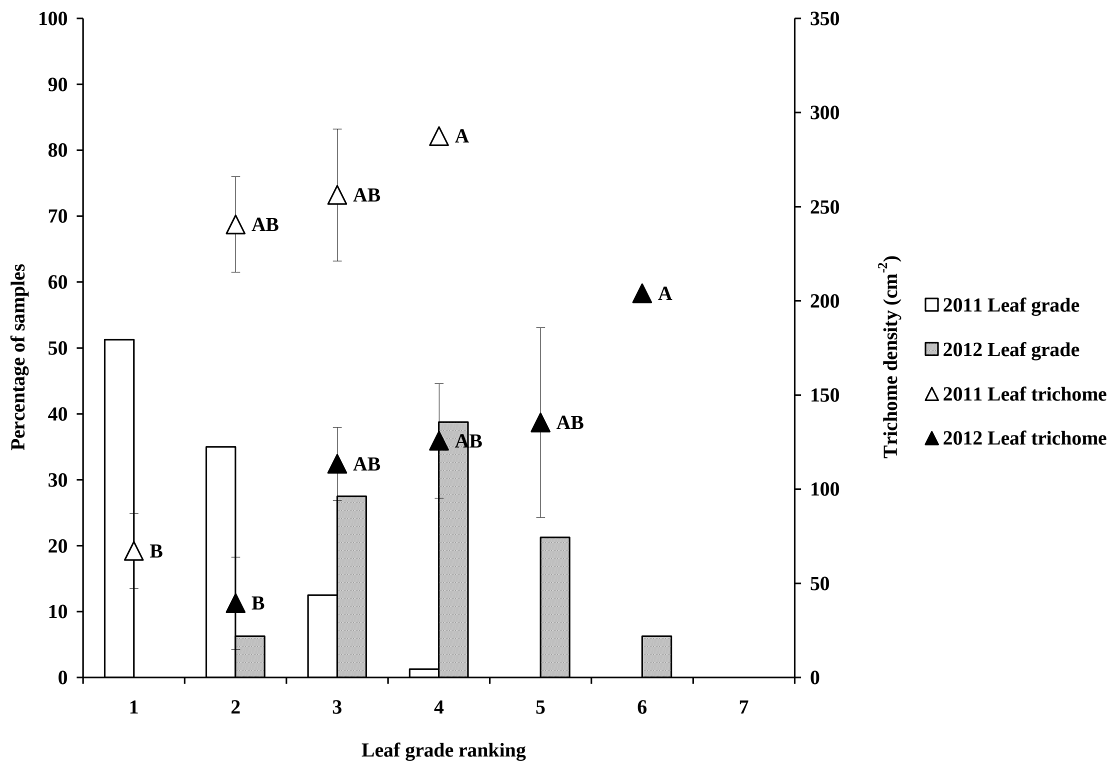



**Figure 15.** Analysis of leaf grade occurrences and leaf trichome density averages for leaf grade categories from cultivar by harvest aid trials conducted in Burleson County during the 2011 and 2012 growing seasons. Two smooth and two hairy leaf cultivars were used for comparison. Kruskal-Wallis test indicated the cotton leaf grade was influenced by trichome density both seasons ($P = 0.05$). Trichome densities averages were significantly different between leaf grade values in both seasons. Means followed by the same letter in the same series are not significantly different (P = 0.05). Error bars represent the standard error of the data.

Locations of the trials in 2010 and 2012 experienced closer to average weather conditions and produced average leaf grade ratings for this region (USDA, 2012; Appendix A and B). Defoliation and harvest aid treatments had no influence on the leaf grade score. Higher leaf grade value occurrences were consistently associated with higher leaf trichome density. Leaf grade increases were achieved despite hairy cultivars producing less than half of the 600 trichome $cm^{-2}$ produced by hairy cultivars selected by Rayburn (1988) and Anthony and Rayburn (1989).

In a growing season when leaf grade scores are average, or above average, these results indicate that cotton leaf trichome density does influence the amount of trash found in ginned lint. Defoliation, desiccation and environmental harvest conditions are vital to a successful harvest in terms of speed and quality; however cultivar selection, primarily leaf hairiness, is important to reducing leaf grade values. Based on finding of this research, the ability to set standards for ranking leaf hairiness of cotton based on leaf trichome densities may be possible with the utilization of accepted standards for comparison between seasons.

# CHAPTER V

# CONCLUSION

The wide range of defoliation and desiccation levels were achieved with the selected harvest aid treatments.  Valco and Snipes (2001) analyzed 16 separate test sites and seven harvest aid treatments, and found only minimal reductions in measurements of trash.  The results of this study indicated that the leaf grade of ginned cotton lint is not directly impacted by the level of defoliation or desiccation, which is consistent with Beltwide data previously collected (Valco and Snipes, 2001).  However, environmental factors throughout the duration of this study prevented the combining of data, which included an abnormally high percentage of leaf grade scores of 1 and 2 in 2011 throughout the region (USDA, 2012).

The differences in environment, which includes, plant condition, application conditions, and weather, were found to have consistent influences on the effectiveness of harvest aid treatments.  This coincides with previous studies finding timing, canopy density, translocation of chemicals, and varietal traits can influence defoliation and desiccation (Cathey, 1986; Oosterhuis et al., 1991).  Variation between years was found within individual treatments, as well as stability between years, for a select few treatments.  The unpredictable trend between years and locations reinforces the practice of field by field harvest aid recommendations.  Ultimately, there were no individual treatments that provided a better leaf grade consistently over multiple years or environments.

For multiple cultivar trial locations across the Cotton Belt have shown that the rating of leaf hairiness assigned to a cultivar by the company does not consistently correspond to an objective quantification of leaf trichome density. The absence of standards increased inconsistencies in the current rating systems and, support the previous efforts by Bourland et al. (2003) and Hornbeck and Bourland (2007) to develop a uniform system. Labeled semi-smooth cultivars were found to have a higher trichome density than all other cultivars in this trial in multiple locations. The rankings of cultivars based on leaf trichome density were similar across locations and years. More dense leaf trichomes were highly correlated with bract trichome densities.

Cotton cultivars with varying levels of leaf trichome density did not impact the defoliation or desiccation efficacy of the harvest aid products. Environmental impacts on harvest aid efficacy have also been reported in previous harvest aid research, and were observed in all trials (Logan and Gwathmey, 2002; Oosterhuis et al., 1991).

Defoliation and harvest aid treatments on various cultivars had no influence on the leaf grade score. Higher leaf grade value occurrences were consistently associated with higher leaf trichome density. Leaf grade increases were achieved despite hairy cultivars producing less than half of the 600 trichome $cm^{-2}$ produced by hairy cultivars selected by Rayburn (1988) and Anthony and Rayburn (1989).

In a growing season when leaf grade scores are average, or above average, these results indicate that cotton leaf trichome density does influence the amount of trash found in ginned lint. Defoliation, desiccation and environmental harvest conditions are vital to a successful harvest in terms of speed and quality; however cultivar selection, primarily leaf hairiness, is important to reducing leaf grade values. Based on finding of this research, the ability to set standards for ranking leaf hairiness of cotton based on leaf trichome densities may be possible with the utilization of accepted standards for comparison between seasons.

LITERATURE CITED

Addicott, F.T. 1982. Abscission. University of California Press. Berkeley.

Anthony, W.S. and S.T. Rayburn. 1989**.** Cleanability of smooth- and hairy-leaf cottons – quality effects. Trans. ASAE 32:1127-1130.

Bennett, B.K., S.K. Misra, and A. Brashears. 1997. Cost/benefit analysis of bur extractors in cotton harvesting. J. Agribusiness 14:189–198.

Bourland, F.M. and J.M. Hornbeck. 2007. Variation in marginal bract trichome density in upland cotton. J. Cotton Sci. 11:242-251.

Bourland, F.M., J.M. Hornbeck, A.B. McFall, and S.D. Calhoun. 2003. A rating system for leaf pubescence of cotton. J. Cotton Sci. 7:8-15.

Bradow, J.M., and L.H. Wartelle. 1998. Fifty-six days in the life of a *Gossypium* cell. p. 1462-1463. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Cathey, G.W. 1986. Physiology of defoliation in cotton production. p. 143-154. *In* J.R. Mauney and J.McD. Stewart (ed.) Cotton Physiology. The Cotton Foundation Reference Book Series, Cotton Foundation, Memphis, TN.

Dimitropoulou, K. Kosmidou, J.D. Berlin, and P.R. Morey. 1980. Capitate hairs on cotton leaves and bracts. Crop Sci. 20:534-537.

Faircloth, J.C., K.L. Edmisten, R. Wells, and A.M. Stewart. 2004. The influence of defoliation timing on yields and quality of two cotton cultivars. Crop Sci. 44: 165-172.

Faulkner, W.B., B.W. Shaw, and E. Hequet. 2008. Effects of harvesting method on foreign matter content, fiber quality, and yarn quality from irrigated cotton on the High Plains. p. 612-619. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 8-11 Jan. Natl. Cotton Counc. Am. Memphis, TN.

Fortenberry, A. J. (1956). Charges for ginning cotton. *In* Marketing Research Report (No. 120). Washington, DC: U.S. Government Printing Office

Guinn, G. 1986. Hormonal relations during reproduction. p. 143-154. *In* J.R. Mauney and J.McD. Stewart (ed.) Cotton Physiology. The Cotton Foundation Reference Book Series, Cotton Foundation, Memphis, TN.

Hornbeck J.M., and F.M. Bourland. 2007. Visual ratings and relationships of trichomes on bracts, leaves, and stems of upland cotton. J. Cotton Sci. 11:252-258.

Jenkins, J.N., and F.D. Wilson. 1996. Host plant resistance. p. 563-597. E.G. King, J.R. Phillips, and R.J. Coleman (eds.). *In* Cotton Insects and Mites: Characterization and Management. Cotton Foundation Reference Book Series. The Cotton Foundation, Memphis, TN.

Larson, J.A., and B.C. English. 2001. Factors influencing net returns to cotton harvest aids. p. 181-203. *In* J.R. Supak and C.E. Snipes (ed.). Cotton Harvest Management: Use and Influence of Harvest Aids. Ref. Book Series No. 5. Cotton Foundation, Memphis, TN.

Larson, J.A., Gwathmey, C.O., and R.M. Hayes. 2005. Effects of defoliation timing and desiccation on net revenues from ultra-narrow-row. Cotton. J. Cotton Sci. 9:204-214.

Lecape, J.M. and T.B. Nguyen. 2005. Mapping quantitative trait loci associated with leaf and stem pubescence in cotton. J. Heredity. 96(4):441-444.

Lewis, C. E, and T. R. Richmond. (1968). Cotton as a crop. p. 1-21. *In* F. C. Elliot, M. Hoover, and W. K. Porter, Jr. (ed.), Advances in Production and Utilization of Quality Cotton: Principles and practices. Iowa State University Press. Ames.

Logan, J. and C.O. Gwathmey. 2002. Effects of weather on cotton responses to harvest aid chemicals. J. Cotton Sci. 6:1-12.

Mekala, D.K. 2004. Screening upland cotton for resistance to cotton fleahopper (Heteroptera: Miridae). Master's thesis, Texas A&M University. College Station, TX. Available electronically from http://hdl.handle.net/1969.1/1071.

Morey, P.R., P.E. Sasser, R.M. Bethea, and M.T. Kopetzky. 1976. Variation in trash composition in raw cottons. Am. Ind. Hyg. Assoc. J. 37:407-412.

Morgan, P.W. 1984. Is ethylene the natural regulator of abscission? p.231-240 *In* Y. Fuchs and E. Chalutz (ed.), Ethylene: Biochemical, Physiological, and Applied Aspects. Boston.

Morgan, P.W., & J.J. Durham. 1975. Ethylene-induced leaf abscission is promoted by gibberellic acid. Plant Physiol. 41:45-52.

Norman, J.W. Jr., and A.N. Sparks, Jr. 1997. Cotton leaf hairs and silverleaf whiteflies in the lower Rio Grande Valley of Texas. p. 1063-1064. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Novick, R.G., J.E. Jones, W.S. Anthony, W. Aguillard, and J.I. Dickson. 1991. Genetic trait effect on nonlint trash of cotton. Crop Sci. 31:1029-1034.

Oosterhuis, D.M., R.E. Hampton, and S.D. Wullschlegar. 1991. Water deficit effects on the leaf cuticle and effiency of defoliants. J. Prod. Agric. 4:260-265.

Oosterhuis, D.M., and J. Jernstedt. 1999. Morphology and anatomy of the cotton plant. p. 175-206. *In* C.W. Smith and J.T. Cothren (ed.) Cotton: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York.

Pederson, M.K., J.D. Buron, H.D. Coble, J.R. Collins, and D. Fritz. 1997. Efficacy of Finish and its mechanism of action. p.1363-1365. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Rayburn, S.T., Jr. 1986. A leaf hairiness index for nine cotton cultivars. p. 474. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 4-9 Jan. 1986. Natl. Cotton Counc. Am., Memphis, TN.

Rayburn, S.T., Jr., and L. Libous. 1983. Preliminary investigation of cleanability of cotton with varying degrees of plant hairiness. p. 152-153. *In* Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX. 2-6 Jan. 1983. Natl. Cotton Counc. Am., Memphis, TN.

SAS Institute. 2007. The SAS system for windows. Release 9.2. SAS Inst. Cary, NC.

Scandalios, J.G. 1993. Correlation of defoliation timing methods to optimize cotton yield, quality, and revenue. J. Cotton Sci. 10:146-154.

Sexton, R.L., L.N. Lewis, and P. Kelly. 1985. Ethylene and abscission. p. 173-196. *In* J.A. Roberts, and G.A. Tucker (ed.), Ethylene and Plant Development, Butterworths. London.

Siebert, J.D. and A.M. Stewart 2006. Correlation of defoliation timing methods to optimize cotton yield, quality, and revenue. J. Cotton Sci. 10:146-154.

Siebert, J.D., A.M. Stewart, D.K. Miller, and C.C. Craig. 2006. Effect of carrier volume and nozzle type on cotton harvest aid efficacy. J. Cotton Sci. 10:89-96.

Smith, A.L. 1964. Leaf trichomes of upland cotton varieties. Crop Sci. 4:348-349.

Snipes, C.E. and C.C. Baskin. 1994. Influence of early defoliation on cotton yield, seed quality, and fiber properties. Field Crops Res. 37:137-143.

Snipes, C.E. and G.W. Cathey. 1992. Evaluation of defoliant mixtures in cotton. Field Crops Res. 28:327-334.

Sui, R., A.J. Thomasson, R.K. Byler, J.C Boykin, and E.M Barnes 2010. Effect of machine-fiber interaction on cotton fiber quality and foreign-matter particle attachment to fiber. J. Cotton Sci. 14:119-127.

Supak, J.R. and J.C. Banks. 2001. Regional defoliation practices – Southwest. p. 237-254. *In* J.R. Supak and C.E. Snipes (ed.). Cotton Harvest Management: Use and Influence of Harvest Aids. Ref. Book Series No. 5. Cotton Foundation, Memphis, TN.

Supak, J.R. and C.E., Snipes. 2001. Cotton Harvest Management: Use and Influence of Harvest Aids. Ref. Book Series No. 5. Cotton Foundation, Memphis, TN.

Suttle, J.C. 1988. Disruption of the polar auxin transport system in cotton seedlings following treatment with the defoliant thidiazuron. Plant Physiol. 86:241-245.

USDA-AMS. 2012. Quality of cotton classed. http://www.ams.usda.gov/mnreports/cnaacq.pdf

Valco, T.D., and C.E. Snipes. 2001. Uniform harvest aid performance and lint quality evaluation. p. 167-180. *In* J.R. Supak and C.E. Snipes (ed.). Cotton Harvest Management: Use and Influence of Harvest Aids. Ref. Book Series No. 5. Cotton Foundation, Memphis, TN.

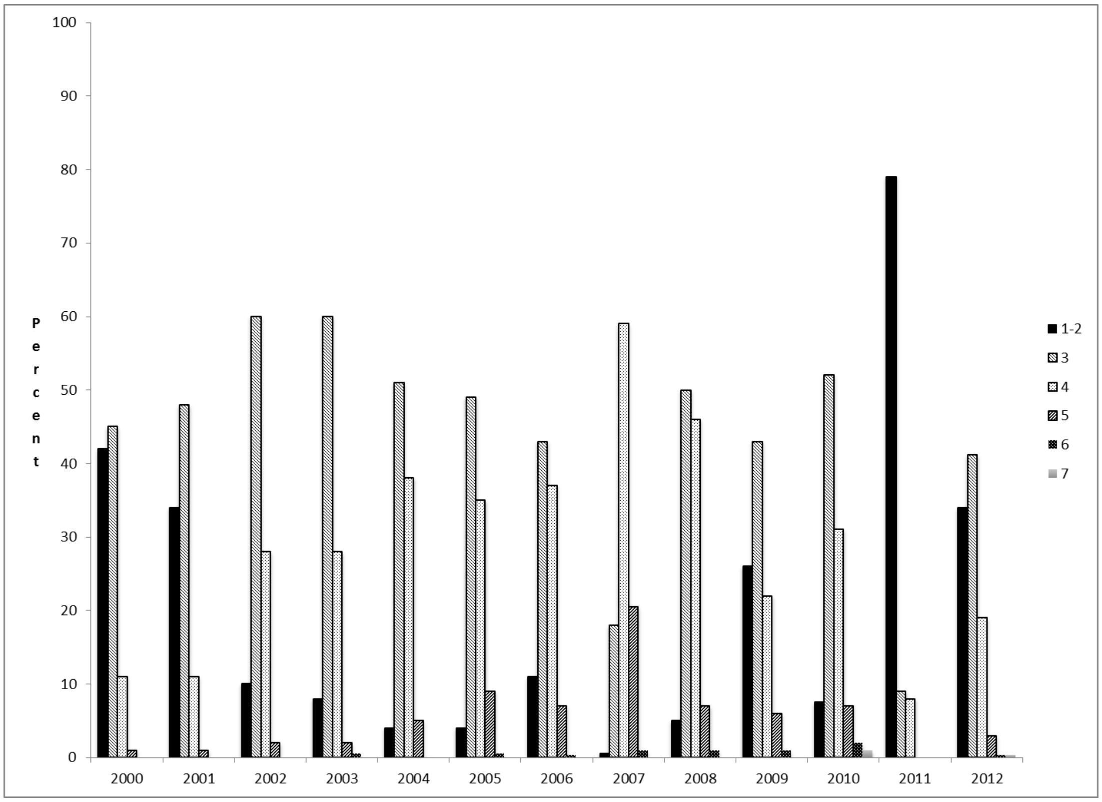
Walhood, V.T., and F.T. Addicott. 1968. Harvest aid programs: Principles and practices. p. 407-431. *In* F.C. Elliot, M. Hoover, and W.K. Porter, Jr. (ed.) Cotton: Principles and Practices. Iowa State University Press. Ames

Wullschleger, S.D., D.M. Oosterhuis, and S.A. Rutherford. 1990. Importance of bracts in the carbon economy of cotton. Ark. Farm Res. 39:4.

Zer, H., and I. Ohad. 1995. Photoinactivation of photosystem II induces changes in the photochemical reaction center II abolishing the regulatory role of the QB site in the D1 protein degradation. Eur. J. Biochem. 231:448-453.

Zhao, D., and D.M. Oosterhuis. 2000. Dynamics of nonstructural carbohydrates in developing leaves, bracts, and floral buds of cotton. Environ. Exp. Botany. 43:185-195.

APPENDIX A




Appendix A. Leaf grade ratings as a percentage of total crop classed in Corpus Christi, Tx since 2000 (USDA, 2012).

APPENDIX B

Appendix B. Weather conditions during data collection and harvest aid application for all trial locations.

| Location | Month | DD15.5[z] | Percipitation (cm)[y] |
|---|---|---|---|
| | | 2010 | |
| Burleson | July | 441 | 3.4 |
| | August | 510 | 0.9 |
| | September | 360 | 14.6 |
| Colorado | July | 432 | 23.9 |
| | August | 493 | 1.1 |
| | September | 390 | 9.3 |
| | | 2011 | |
| Burleson | July | 493 | 5.7 |
| | August | 536 | 0.6 |
| | September | 393 | 0.3 |
| Matagorda | July | 447 | 0.6 |
| | August | 475 | 0.4 |
| | September | 381 | 2.5 |
| Nueces | July | 465 | 2.2 |
| | August | 512 | 0.2 |
| | September | 420 | 2.2 |
| Williamson | July | 465 | 0.1 |
| | August | 512 | 0.3 |
| | September | 375 | 2.5 |
| | | 2012 | |
| Burleson | July | 424 | 11.5 |
| | August | 475 | 4.3 |
| | September | 352 | 8.2 |
| Colorado | July | 388 | 15.8 |
| | August | 419 | 3.7 |
| | September | 315 | 0.9 |
| Georgia | July | 419 | 0 |
| | August | 372 | 0 |
| | September | 315 | 0 |
| Matagorda | July | 415 | 8.1 |
| | August | 441 | 6.1 |
| | September | 368 | 12.4 |
| San Patricio | July | 435 | 3.4 |
| | August | 481 | 0.3 |
| | September | 405 | 9.1 |
| Williamson | July | 403 | 6.2 |
| | August | 434 | 8 |
| | September | 300 | 5.7 |

[z]Total degree days calculated at 15.5 degrees Celsius in each month.

[y]Total precipitation accumulated during each month.

# APPENDIX C

Appendix C. Plant regrowth 14 days after application of harvest aid treatments.

| ID | Treatment[z] | g AI $ha^{-1}$ | Timing | Burleson 2011 Regrowth (%)[y] | Burleson 2012 Regrowth (%) | Matagorda 2011 Regrowth (%) | Colorado 2012 Regrowth (%) |
|---|---|---|---|---|---|---|---|
| 1 | Thidiazuron | 56 | A[v] | 2.25 ef | 29.7 a | 0.5 e | 0.5 a |
| | Thidiazuron | 56 | B | | | | |
| 2 | Thidiazuron | 28 | A | 6.75 abcde | 12.5 a | 0.75 de | 0 a |
| | Ethephon | 2205 | A | | | | |
| 3 | Ethephon | 1103 | A | | | | |
| 4 | Thidiazuron | 28 | A | | | | |
| 5 | Thidiazuron | 112 | A | 2.5 ef | 18.6 a | 0.25 e | 1.0 a |
| 6 | Thidiazuron | 56 | A | | | | |
| | Ethephon | 1103 | A | | | | |
| 7 | Thidiazuron | 112 | A | 9.25 abc | 12.0 a | 1.25 de | 3.75 a |
| | Ethephon | 1103 | A | | | | |
| 8 | Thidiazuron | 56 | A | | | | |
| | Tribufos | 210 | A | | | | |
| 9 | Thidiazuron | 56 | A | 10 ab | 24.0 a | 3.75 abc | 1.5 a |
| | Tribufos | 210 | A | | | | |
| | Ethephon | 1103 | A | | | | |
| 10 | Thidiazuron + Diuron | 26 + 13 | A | 8.75abcd | 7.0 a | 3.75 abc | 2.5 a |
| 11 | Ethephon + Cyclanilide | 1103 + 69 | A | 3.25 def | 40.0 a | 4.75 ab | 8.5 a |
| 12 | Thidiazuron + Diuron | 18.5 + 9 | A | 9.25 abc | 20.8 a | 6.0 a | 8.0 a |
| | Ethephon + Cyclanilide | 1103 + 69 | A | | | | |
| 13 | Carfentrazone-ethyl[x] | 17.5 | A | 4.25 cdef | 28.0 a | 0.25 e | 25.3 a |
| 14 | Pyraflufen ethyl[x] | 2.7 | A | 2.25 ef | 28.2 a | 2.0 cde | 2.75 a |
| 15 | Paraquat[w] | 560 | A | 0.5 f | 13.3 a | 3.0 bcd | 0 a |
| 16 | Thidiazuron | 56 | A | 3.5 def | 24.8 a | 0.5 e | 1.0 a |
| | Carfentrazone-ethyl[x] | 17.5 | B | | | | |
| 17 | Thidiazuron | 56 | A | 6.75 abcde | 9.0 a | 0.75 de | 0.75 a |
| | Paraquat[w] | 560 | B | | | | |
| 18 | Thidiazuron | 112 | A | 10.5 a | 11.5 a | 1.0 de | 3.5 a |
| | Tribufos | 315 | A | | | | |
| | Ethephon | 1103 | A | | | | |
| 19 | Thidiazuron | 56 | A | 4.5 bcdef | 7.5 a | 0.5 e | 1.5 a |
| | Thidiazuron + Diuron | 26 + 13 | B | | | | |
| 20 | Untreated ($H_2O$) | 0 | A | 0 f | 0 a | 0 e | 0 a |
| Pr>F | | | | <0.01 | 0.35 | <0.01 | 0.5 |
| Mean | | | | 5.27 | 17.8 | 1.81 | 3.78 |

[z]Treatments applied at 102.9 L $Ha^{-1}$

[y]Means followed by the same letter in a column, within a specific environment, are not significantly different (P = 0.05).

[x] indicates NIS was added at a 0.25% v/v rate

[w] indicates Crop Oil Concentrate was added at a 1% v/v rate

[v]Timings of treatments B were 7 days after application of treatments A

APPENDIX D

Appendix D.1. Probabilities associated with sources of variation for defoliation and desiccation values of harvest aid treatments at Burleson, Colorado, and Matagorda Counties, 2010 to 2012.

| Sources of variation | Defoliation | Desiccation |
|---|---|---|
| Site-Year (SY) | <0.01 | <0.01 |
| Rep(SY) | 0.54 | 0.72 |
| Treatment (T) | <0.01 | <0.01 |
| SY*T | <0.01 | <0.01 |

Appendix D.2. Probabilities associated with sources of variation for morphological parameters of cultivars in cultivar trials in 2011 to 2012.

| Sources of variation | Leaf Trichomes | Bract Trichomes | Leaf Area | Bract Area | Bract Length |
|---|---|---|---|---|---|
| Site-Year (SY) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Rep(SY) | 0.01 | 1 | <0.01 | 0.12 | 0.04 |
| Cultivars (C) | <0.01 | <0.01 | 0.09 | <0.01 | <0.01 |
| SY*C | <0.01 | <0.01 | 0.03 | 0.06 | 0.18 |

Appendix D.3. Probablities associated with sources of variation of defoliation and desiccation parameters of multiple cultivars in Colorado and Matagorda Counties, 2010 to 2012.

| Sources of variation | Defoliation | Desiccation |
|---|---|---|
| Year (Y) | <0.01 | <0.01 |
| Rep(year) | 0.66 | 0.46 |
| Cultivars (C) | 0.04 | 0.3 |
| C*Y | 0.52 | 0.61 |
| Treatment (T) | <0.01 | <0.01 |
| T*Y | <0.01 | <0.01 |
| C*T | 0.6 | 0.58 |
| C*T*Y | 0.19 | 0.39 |

Appendix D.4. Probablities associated with sources of variation for morphological parameters of multiple cultivars in Colorado and Matagorda Counties, 2010 to 2012.

| Sources of variation | Leaf Trichomes | Bract Trichomes | Leaf Area | Bract Area | Bract Length |
|---|---|---|---|---|---|
| Year (Y) | 0.22 | 0.04 | <0.01 | <0.01 | <0.01 |
| Rep(Y) | <0.01 | <0.01 | <0.01 | 0.12 | <0.01 |
| Cultivars (C) | <0.01 | <0.01 | 0.17 | <0.01 | <0.01 |
| Y*C | <0.01 | <0.01 | 0.03 | <0.01 | <0.01 |

Appendix D.5. Probabilities associated with sources of variation of defoliation and desiccation parameters of multiple cultivars in Burleson County, 2011 to 2012.

| Sources of variation | Defoliation | Desiccation |
|---|---|---|
| Year (Y) | 0.28 | <0.01 |
| Rep(year) | <0.01 | 0.02 |
| Cultivars (C) | 0.56 | 0.35 |
| C*Y | 0.55 | 0.77 |
| Treatment (T) | <0.01 | <0.01 |
| T*Y | <0.01 | <0.01 |
| C*T | 0.61 | 0.75 |
| C*T*Y | 0.12 | 0.95 |

Appendix D.6. Probabilities associated with sources of variation for morphological parameters of cultivars in Burleson County, 2011 to 2012.

| Sources of variation | Leaf Trichomes | Bract Trichomes | Leaf Area | Bract Area | Bract Length |
|---|---|---|---|---|---|
| Site-Year (SY) | 0.13 | 0.03 | 0.66 | <0.01 | 0.11 |
| Rep(SY) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cultivars (C) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| SY*C | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

## APPENDIX E

Appendix E.1. Correlations of morphological traits and leaf grade for cultivar in Nueces County during 2011.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.48 | 0.14 | -0.15 | 0.05 | 0.15 |
| Pr>F | | 0.04 | 0.59 | 0.54 | 0.84 | 0.56 |
| Bract Trichomes | | 1 | 0.35 | 0.38 | 0.45 | 0.18 |
| Pr>F | | | 0.15 | 0.12 | 0.06 | 0.47 |
| Leaf Area | | | 1 | 0.58 | 0.4 | 0.15 |
| Pr>F | | | | 0.01 | 0.1 | 0.55 |
| Bract Area | | | | 1 | 0.83 | 0.33 |
| Pr>F | | | | | <0.01 | 0.18 |
| Bract Length | | | | | 1 | 0.47 |
| Pr>F | | | | | | 0.05 |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)

Appendix E.2. Correlations of morphological traits and leaf grade for cultivar in San Patricio County during 2012.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.66 | -0.25 | -0.12 | 0.13 | 0.37 |
| Pr>F | | <0.01 | 0.27 | 0.6 | 0.57 | 0.1 |
| Bract Trichomes | | 1 | -0.23 | -0.06 | 0.05 | 0.22 |
| Pr>F | | | 0.31 | 0.8 | 0.83 | 0.35 |
| Leaf Area | | | 1 | 0.57 | 0.37 | 0.16 |
| Pr>F | | | | <0.01 | 0.1 | 0.49 |
| Bract Area | | | | 1 | 0.55 | -0.06 |
| Pr>F | | | | | 0.01 | 0.78 |
| Bract Length | | | | | 1 | 0.19 |
| Pr>F | | | | | | 0.41 |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)

Appendix E.3. Correlations of morphological traits and leaf grade for cultivar in Matagorda County during 2011.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.74 | 0.07 | 0.28 | -0.09 | 0.71 |
| Pr>F | | <0.01 | 0.77 | 0.27 | 0.72 | <0.01 |
| Bract Trichomes | | 1 | -0.22 | -0.1 | -0.24 | 0.62 |
| Pr>F | | | 0.38 | 0.7 | 0.33 | <0.01 |
| Leaf Area | | | 1 | 0.69 | 0.57 | 0.11 |
| Pr>F | | | | <0.01 | 0.01 | 0.67 |
| Bract Area | | | | 1 | 0.77 | 0.41 |
| Pr>F | | | | | <0.01 | 0.1 |
| Bract Length | | | | | 1 | 0 |
| Pr>F | | | | | | 1 |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test (P≤0.05): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test (P≤0.05)

Appendix E.4. Correlations of morphological traits and leaf grade for cultivar in Matagorda County during 2012.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.54 | 0.13 | 0.27 | 0.2 | 0.76 |
| Pr>F | | 0.01 | 0.59 | 0.24 | 0.4 | <0.01 |
| Bract Trichomes | | 1 | 0.31 | -0.18 | -0.1 | 0.48 |
| Pr>F | | | 0.18 | 0.44 | 0.67 | 0.03 |
| Leaf Area | | | 1 | 0 | -0.19 | 0.15 |
| Pr>F | | | | 1 | 0.43 | 0.52 |
| Bract Area | | | | 1 | 0.8 | 0.09 |
| Pr>F | | | | | <0.01 | 0.71 |
| Bract Length | | | | | 1 | 0.07 |
| Pr>F | | | | | | 0.76 |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)

Appendix E.5. Correlations of morphological traits and leaf grade for cultivar in Williamson County during 2011.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.8 | -0.2 | 0.05 | -0.44 | - |
| Pr>F | | <0.01 | 0.42 | 0.84 | 0.07 | - |
| Bract Trichomes | | 1 | -0.33 | 0 | -0.17 | - |
| Pr>F | | | 0.18 | 0.99 | 0.5 | - |
| Leaf Area | | | 1 | 0.33 | 0.41 | - |
| Pr>F | | | | 0.18 | 0.09 | - |
| Bract Area | | | | 1 | 0.54 | - |
| Pr>F | | | | | 0.02 | - |
| Bract Length | | | | | 1 | - |
| Pr>F | | | | | | - |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test (P≤0.05): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test (P≤0.05)

Appendix E.6. Correlations of morphological traits and leaf grade for cultivar in Williamson during 2012.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.63 | - | - | - | 0.38 |
| Pr>F | | <0.01 | - | - | - | 0.12 |
| Bract Trichomes | | 1 | - | - | - | -0.23 |
| Pr>F | | | - | - | - | 0.37 |
| Leaf Area | | | 1 | - | - | - |
| Pr>F | | | | - | - | - |
| Bract Area | | | | 1 | - | - |
| Pr>F | | | | | - | - |
| Bract Length | | | | | 1 | - |
| Pr>F | | | | | | - |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)

Appendix E.7. Correlations of morphological traits and leaf grade for cultivar in Tifton, Georgia during 2012.

| | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Leaf Grade[y] |
|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.51 | 0.14 | 0.55 | 0.42 | 0.07 |
| Pr>F | | 0.03 | 0.56 | 0.01 | 0.07 | 0.76 |
| Bract Trichomes | | 1 | 0.25 | 0.62 | 0.38 | 0.12 |
| Pr>F | | | 0.3 | <0.01 | 0.11 | 0.62 |
| Leaf Area | | | 1 | 0.26 | 0.07 | 0.05 |
| Pr>F | | | | 0.26 | 0.77 | 0.82 |
| Bract Area | | | | 1 | 0.87 | -0.03 |
| Pr>F | | | | | <0.01 | 0.89 |
| Bract Length | | | | | 1 | -0.05 |
| Pr>F | | | | | | 0.83 |
| Leaf Grade | | | | | | 1 |

[z]Morphological traits were analyzed with a Pearson Correlation test (P≤0.05): Leaf trichome, bract trichome, leaf area, bract area, and bract length.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test (P≤0.05)

## APPENDIX F

Appendix F.1. Correlations of morphological traits and defoliation treatments, and their interaction with leaf grade for cultivar by harvest aid trials in the Upper Coastal Bend of Texas during 2011 and 2012.

| Matagorda 2011 | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Defoliation | Desiccation | Leaf Grade[y] |
|---|---|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.83 | 0.28 | 0.71 | -0.1 | -0.08 | 0.01 | 0.41 |
| Pr>F | | <0.01 | 0.08 | <0.01 | 0.55 | 0.63 | 0.95 | <0.01 |
| Bract Trichomes | | 1 | -0.15 | 0.41 | 0.05 | -0.07 | -0.06 | 0.44 |
| Pr>F | | | 0.36 | <0.01 | 0.77 | 0.68 | 0.69 | <0.01 |
| Leaf Area | | | 1 | 0.27 | -0.15 | -0.04 | 0.02 | -0.03 |
| Pr>F | | | | 0.1 | 0.36 | 0.8 | 0.89 | 0.84 |
| Bract Area | | | | 1 | -0.24 | -0.08 | 0.1 | 0.33 |
| Pr>F | | | | | 0.13 | 0.64 | 0.54 | 0.04 |
| Bract Length | | | | | 1 | 0.14 | -0.29 | -0.39 |
| Pr>F | | | | | | 0.39 | 0.07 | 0.01 |
| Defoliation | | | | | | 1 | 0.38 | -0.01 |
| Pr>F | | | | | | | 0.02 | 0.94 |
| Desiccation | | | | | | | 1 | -0.03 |
| Pr>F | | | | | | | | 0.84 |
| Leaf Grade | | | | | | | | 1 |
| Pr>F | | | | | | | | |
| **Colorado 2012** | **Leaf Trichomes** | **Bract Trichomes** | **Leaf Area** | **Bract Area** | **Bract Length** | **Defoliation** | **Desiccation** | **Leaf Grade** |
| Leaf Trichomes | 1 | 0.97 | 0 | 0.58 | 0.75 | -0.19 | 0.11 | 0.47 |
| Pr>F | | <0.01 | 0.97 | <0.01 | <0.01 | 0.23 | 0.52 | <0.01 |
| Bract Trichomes | | 1 | -0.17 | 0.52 | 0.68 | -0.19 | 0.11 | 0.36 |
| Pr>F | | | 0.3 | <0.01 | <0.01 | 0.24 | 0.51 | 0.02 |
| Leaf Area | | | 1 | 0.66 | 0.53 | -0.07 | -0.16 | 0.34 |
| Pr>F | | | | <0.01 | <0.01 | 0.67 | 0.31 | 0.03 |
| Bract Area | | | | 1 | 0.66 | -0.13 | 0.22 | 0.46 |
| Pr>F | | | | | <0.01 | 0.42 | 0.18 | <0.01 |
| Bract Length | | | | | 1 | -0.2 | -0.05 | 0.48 |
| Pr>F | | | | | | 0.22 | 0.74 | <0.01 |
| Defoliation | | | | | | 1 | 0.18 | -0.32 |
| Pr>F | | | | | | | 0.28 | 0.04 |
| Desiccation | | | | | | | 1 | 0.21 |
| Pr>F | | | | | | | | 0.19 |
| Leaf Grade | | | | | | | | 1 |
| Pr>F | | | | | | | | |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, bract length, defoliation, and desiccation.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)

Appendix F.2. Correlations of morphological traits and defoliation treatments, and their interaction with leaf grade for cultivar by harvest aid trials in Burleson County during 2011 and 2012.

| Burleson 2011 | Leaf Trichomes[z] | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Defoliation | Desiccation | Leaf Grade[y] |
|---|---|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.72 | 0.14 | -0.57 | -0.48 | -0.7 | 0.03 | 0.53 |
| Pr>F | | <0.01 | 0.23 | <0.01 | <0.01 | 0.52 | 0.81 | <0.01 |
| Bract Trichomes | | 1 | 0.35 | -0.58 | -0.35 | -0.06 | -0.08 | 0.41 |
| Pr>F | | | <0.01 | <0.01 | <0.01 | 0.6 | 0.5 | <0.01 |
| Leaf Area | | | 1 | -0.21 | -0.32 | -0.06 | -0.1 | -0.26 |
| Pr>F | | | | 0.06 | <0.01 | 0.58 | 0.4 | 0.05 |
| Bract Area | | | | 1 | 0.68 | 0.04 | 0.1 | -0.21 |
| Pr>F | | | | | <0.01 | 0.74 | 0.37 | 0.06 |
| Bract Length | | | | | 1 | 0.11 | 0.15 | -0.16 |
| Pr>F | | | | | | 0.33 | 0.18 | 0.16 |
| Defoliation | | | | | | 1 | 0.38 | -0.09 |
| Pr>F | | | | | | | <0.01 | 0.41 |
| Desiccation | | | | | | | 1 | 0.08 |
| Pr>F | | | | | | | | 0.46 |
| Leaf Grade | | | | | | | | 1 |
| Pr>F | | | | | | | | |

| Burleson 2012 | Leaf Trichomes | Bract Trichomes | Leaf Area | Bract Area | Bract Length | Defoliation | Desiccation | Leaf Grade |
|---|---|---|---|---|---|---|---|---|
| Leaf Trichomes | 1 | 0.72 | -0.27 | -0.75 | -0.75 | -0.03 | -0.11 | 0.17 |
| Pr>F | | <0.01 | 0.01 | <0.01 | <0.01 | 0.81 | 0.37 | <0.01 |
| Bract Trichomes | | 1 | -0.2 | -0.76 | -0.69 | -0.06 | -0.27 | 0.11 |
| Pr>F | | | 0.1 | <0.01 | <0.01 | 0.62 | 0.02 | 0.38 |
| Leaf Area | | | 1 | 0.25 | 0.38 | -0.09 | 0.09 | -0.01 |
| Pr>F | | | | 0.03 | <0.01 | 0.43 | 0.44 | 0.92 |
| Bract Area | | | | 1 | 0.91 | -0.01 | 0.02 | -0.28 |
| Pr>F | | | | | <0.01 | 0.96 | 0.84 | 0.01 |
| Bract Length | | | | | 1 | 0 | 0 | -0.29 |
| Pr>F | | | | | | 1 | 1 | <0.01 |
| Defoliation | | | | | | 1 | 0.24 | -0.1 |
| Pr>F | | | | | | | 0.04 | 0.41 |
| Desiccation | | | | | | | 1 | 0.08 |
| Pr>F | | | | | | | | 0.47 |
| Leaf Grade | | | | | | | | 1 |
| Pr>F | | | | | | | | |

[z]Morphological traits were analyzed with a Pearson Correlation test ($P \leq 0.05$): Leaf trichome, bract trichome, leaf area, bract area, bract length, defoliation, and desiccation.

[y]Leaf grade correlations were analyzed with a Spearman Correlation test ($P \leq 0.05$)